

PHYTOPLANKTON SPECIES COMPOSITION, ABUNDANCE, AND  
DISTRIBUTION IN SOUTHERN LAKE HURON, 1980; INCLUDING  
A COMPARATIVE ANALYSIS WITH CONDITIONS IN 1974  
PRIOR TO NUTRIENT LOADING REDUCTIONS

by

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Special Report No. 107  
Great Lakes Research Division  
The University of Michigan  
Ann Arbor, Michigan

1985

## ABSTRACT

Analysis of 1980 southern Lake Huron phytoplankton indicates that algal populations observed are representative of the entire trophic spectrum found in the Great Lakes today. Assemblages observed in the open waters of the central and southern basins of Lake Huron typically develop under oligotrophic or meso-oligotrophic conditions and indicate fairly high water quality. However, some populations characteristic of eutrophy are present in the study area and are associated with Saginaw Bay, Thunder Bay, and the nearshore zones southward from these areas. Typically, nearshore zones contain elevated algal abundances compared to offshore waters and correspond to nutrient loading gradients. The nearshore zone between Alpena and Tawas City, Michigan, appears to be more enriched than previously realized. The offshore waters of the central and southern basins show greater average phytoplankton abundance in 1980 compared to 1974. Also, several oligotrophic species observed in the offshore waters during 1974 were significantly reduced in 1980. In general, offshore zones exhibit decreases in oligotrophic diatom species and increases in microflagellate abundance between years. The Canadian nearshore zone in the southern basin similarly exhibits lower diatom abundances and higher cell densities of flagellate species. A considerable decrease in total phytoplankton standing crop was observed in outer Saginaw Bay in 1980, apparently in response to reduced nutrient loadings during the time period. Also, several species representative of eutrophic conditions in 1974, particularly blue-greens such as Aphanizomenon flos-aquae, Anabaena subcylindrica, and Oscillatoria retzii, were not observed in outer Saginaw Bay in 1980. Similarly, other species highly associated with eutrophic conditions

in Saginaw Bay during 1974 such as Fragilaria capucina, Stephanodiscus binderanus, Actinocyclus normanii fo. subsalsa, Anabaena flos-aquae, and Gloeotila sp. were substantially reduced in 1980. During 1974, Saginaw Bay-generated populations appeared to be widely dispersed to the central and southern basins by water mass circulation. However, algal distributions and the results of principal component analysis indicate that the transport of Saginaw Bay populations was not as extensive during 1980. Algal populations characteristic of Saginaw Bay were typically confined to outer Saginaw Bay in 1980. Algal transport was not readily detected during 1980. This was apparently due to greatly reduced standing crops of species highly associated with Saginaw Bay, resulting from nutrient control measures instituted in the Saginaw Bay watershed between 1974 and 1980.

#### ACKNOWLEDGMENTS

The authors would like to express their appreciation to the many persons that were essential in the completion of this project. The crews of the R/V ROGER R. SIMONS and the CSS LIMNOS provided excellent working conditions throughout the course of this study. The authors would like to acknowledge the superior shipboard work of Diane Lazinsky, Edward Theriot, and Marc Tuchman in the collection and processing of samples. R. Jan Stevenson and Linda Sicko-Goad also deserve our gratitude for their contributions. Sandra Krecic provided exceptional graphic representations of the data.

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## INTRODUCTION

Lake Huron is the fifth largest freshwater lake in the world with a surface area of approximately  $60,000 \text{ km}^2$ , volume of  $3,500 \text{ km}^3$ , and a mean depth of 53 m (Schelske 1975). It occupies a hydrologically central position in the Laurentian Great Lakes system. The outflow of Lake Michigan enters Lake Huron through the Straits of Mackinac, and Lake Huron also receives input from Lake Superior via the St. Marys River. Lake Huron then discharges through the St. Clair and Detroit river systems to the lower Great Lakes.

Lake Huron can be divided into six morphometric regions. It possesses two large embayments, Saginaw Bay and Georgian Bay, of which the latter is the larger. The North Channel lies to the west of Georgian Bay and is the northernmost border of the lake. The main lake body is comprised of the northern, central, and southern basins.

Lake Huron serves as an international boundary between Ontario, Canada, and Michigan, U.S.A. Although human population development has not been as extensive as in other areas surrounding the Great Lakes, Lake Huron's present and potential importance to the United States and Canada in terms of industry, municipal usage and recreation is easily perceived.

The phytoplankton assemblages of Lake Huron include populations representative of the entire trophic spectrum found in the Great Lakes today. Vollenweider et al. (1974) has summarized the trophic status of Lake Huron, noting that certain localities differ greatly from the remainder of the lake. Georgian Bay, the North Channel, and the north and central basins exhibit oligotrophic conditions with representative phytoplankton populations and very low standing crops. However, degradation has occurred at nearshore

localities in Georgian Bay (Veal and Michalski 1971, Nicholls et al. 1977a) and in the central basin at Alpena, Michigan (Michigan Water Resources Commission 1976, Lowe 1976, Ladewski et al. 1982).

In contrast to Georgian Bay, Saginaw Bay exhibits a hypereutrophic state evidenced by large phytoplankton standing crops, high  $^{14}\text{C}$  productivity, and high concentrations of nutrients and chlorophyll a (Vollenweider et al. 1974, Smith et al. 1977, Stoermer et al. 1982). Freedman (1974) has discussed the long history of eutrophication, taste and odor problems, and conservative ion loadings in Saginaw Bay. In terms of phytoplankton species composition and standing crop, Saginaw Bay possesses perhaps the poorest water quality in the Great Lakes, rivaled only by the western end of Lake Erie and southern Green Bay. Eutrophy in Saginaw Bay is compounded by other anthropogenic loadings which may produce hidden synergistic effects (Beeton 1965, Fitchko and Hutchinson 1975, Meyers et al. 1980).

The southern basin of Lake Huron has long been considered to have high water quality. Recently, phytoplankton assemblages have indicated this region may be more closely aligned with mesotrophic conditions (Stoermer and Kreis 1980). The influential factors are not completely known, although nearshore inputs from both Canada and the U.S. plus the input from Saginaw Bay, may be producing noticeable effects which follow the eutrophication sequence as observed by Beeton and Edmondson (1972).

Accelerated eutrophication has been recognized in the Great Lakes for a number of years and resultant changes in the biota have been documented for several trophic levels (Beeton 1965, Patalas 1972, Smith 1972, Stoermer 1978). Phosphorus has been identified as having the most profound effects in advancing eutrophication (Schindler 1977, Chapra and Robertson 1977). Several

studies have shown a positive correlation in phosphorus-chlorophyll a relationships (Vollenweider 1968, Schindler et al. 1973, Schindler 1978, Nicholls and Dillon 1978). The importance of phosphorus in algal production has also been demonstrated for the Great Lakes (Schelske et al. 1972, Schelske et al. 1974b, Schelske et al. 1975, Stoermer et al. 1978) and the consequences examined (Schelske and Stoermer 1972, Stoermer 1978). Experimental culture studies on Lake Huron phytoplankton showed that phosphorus was the single most important nutrient influencing algal production (Gotham and Rhee 1981, Lin and Schelske 1981).

Between 1974 and 1980, the U.S. Environmental Protection Agency recorded a 56% total phosphorus loading reduction in Saginaw Bay due to upgraded sewage treatment facilities and a phosphorus detergent ban (Bierman et al. 1984). Chlorophyll a concentrations have been continuously monitored in Saginaw Bay and a 50% (average) chlorophyll a decrease was observed during the time period (Bierman et al. 1984). The present study compares southern Lake Huron phytoplankton species composition, abundance, and distribution during 1974 to those observed in 1980, as they relate to nutrient loading reductions.

Phytoplankton and chlorophyll a concentrations have been studied during lake recovery following phosphorus abatement in the Great Lakes (Vallentyne et al. 1970; Nicholls et al. 1977b, 1980; Nicholls 1981), in the Great Lakes drainage basin (Michalski and Conroy 1973, Sweeney 1973, Dillon et al. 1978), and elsewhere (Edmondson 1972, Schindler 1974, Ahlgren 1978). These studies indicate that the response to phosphorus removal is a reduction in algal standing crop accompanied by a species composition change. Usually there is a reduction in nuisance species; however, each system responds differently and there is no consistent species composition end-point.

Lake Huron algal studies date back to the early 1840s and apparently constitute the earliest systematic algal records for the Great Lakes. A preliminary chronology of Lake Huron algal studies through 1983 is presented in Appendix I. These studies can be divided into three main time groups: 1) pre-1900, 2) 1900-1960, and 3) 1960 to the present. For the most part, studies during the first two periods are few and are of local or peripheral interest. Macroscopic attached algae have been studied through all time periods (Bailey 1847; Klugh 1911, 1915; Herbst 1969) and more recently by Auer and Canale (1980) and Stevenson and Stoermer (1982a, 1982b). However, studies on Lake Huron phytoplankton have been largely neglected. The first quantitative investigations of Lake Huron phytoplankton assemblages were conducted in 1960 (U.S. Public Health Service 1961). Only during the past decade has more intensive sampling produced consistent phytoplankton data regarding species composition, abundance, and distribution (Schelske et al. 1974a; Lowe 1976; Nicholls et al. 1977a; Munawar 1977; Munawar and Munawar 1979a, 1979b; Stoermer and Kreis 1980).

Marine algal assemblages have been shown to be characteristic of certain water masses, particularly in regard to thermal regimes, and are useful tracers of ocean circulation and current patterns (Braarud et al. 1953, Marshall 1971, Motoda and Minoda 1974). Recently this principle has been applied to discriminating water masses in the Laurentian Great Lakes (Schelske et al. 1974a, Holland and Claflin 1975, Stoermer et al. 1976, Stoermer and Kreis 1980, Kreis et al. 1983). In these studies, water mass differentiation resulted from contrasting algal assemblages based on either their habitat preference or trophic association resulting from nutrient loading.

Schelske et al. (1974a) observed latitudinal differences in Lake Huron phytoplankton species composition and abundance indicating differing degrees of eutrophication. Of particular interest, phytoplankton populations indicative of Saginaw Bay were dispersed, under certain conditions, to the open waters of Lake Huron. Stoermer et al. (1976) showed that algal assemblages from Lake Michigan, particularly blue-green algae, were transported to northern Lake Huron through the Straits of Mackinac. Vollenweider et al. (1974) and Lowe (1976) found that the phytoplankton assemblages of Saginaw Bay were unlike those of the open lake. Similarly, Stoermer and Kreis (1980) observed that the assemblages of Saginaw Bay were distinct and may be used to trace the Saginaw Bay water mass entering southern Lake Huron.

The circulatory flows of Saginaw Bay and Lake Huron have been recently studied (Richardson 1974, 1976; Sloss and Saylor 1975, Allender and Green 1976, Danek and Saylor 1977, Saylor and Miller 1979, Schelske et al. 1980). These studies show that Saginaw Bay may discharge to the southern basin in several different patterns. Under prevailing southwest winds, the dominant flow of the Saginaw Bay water mass discharges to the southern basin around the thumb region, then moves southward along the U.S. coast of the southern basin. Fluctuations in the position of the bay-lake interface and the physical, chemical, and biological properties associated with the front have been discussed by Moll et al. (1980).

In Lake Huron, several populations had their greatest abundances in Saginaw Bay with decreasing cell numbers moving away from the bay (Stoermer and Kreis 1980). Their distributions imply that they are generated in Saginaw Bay and transported toward the open lake. Apparently these populations are

senescent but may act as seed populations, becoming restimulated after transport to other areas of high nutrient input.

The implications of algal transport, particularly in this case, are numerous. Algal assemblages transported from Saginaw Bay may have a substantial impact on the production of open lake assemblages. The large phytoplankton biovolume generated in the bay sequesters considerable amounts of nutrients bound in particulate form. Luxury uptake by phytoplankton (as in the formation of polyphosphate bodies) has been observed in certain Saginaw Bay populations (Stoermer et al. 1980). After death and cell decomposition, nutrients are released and may be assimilated by open lake populations.

An important ramification to be considered concerns algal competition. Euplanktonic assemblages are in competition for the low nutrient concentrations found in the open waters and are well adapted for uptake under these circumstances. Although added nutrients may temporarily reduce competition between open lake forms (however increasing standing crop), new populations may be introduced to the open waters which need not be as efficient at nutrient uptake, adding a new dimension to open lake algal competition.

Allochthonous materials (e.g., organic compounds and heavy metals) which originate from point sources may be detected at distances farther than their suspected range when sorbed by transported phytoplankton. Comparatively high concentrations of PCBs have been observed in the Saginaw basin adjacent to the bay (Frank et al. 1979) and along with other anthropogenic substances, may be contributed by transported phytoplankton. Similarly, resuspended materials from sediments may be relocated and redeposited through this mechanism.

The objectives for this project are to:

- 1) Determine the phytoplankton species composition, abundance, and distribution in southern Lake Huron during 1980, and then compare and contrast these features to conditions observed in 1974.
- 2) Assess the degree (dispersal and direction) to which Saginaw Bay-derived phytoplankton are transported to southern Lake Huron in 1980, and then compare and contrast patterns to those identified during 1974.
- 3) Assess the differences observed in southern Lake Huron phytoplankton between years in regard to the nutrient abatement program instituted for the Saginaw River watershed between 1974 and 1980.

## CONCLUSIONS AND RECOMMENDATIONS

The algal flora of southern Lake Huron in 1980 encompassed the extremes of the trophic spectrum, ranging from oligotrophic to eutrophic.

Phytoplankton assemblages in the offshore waters of southern and central Lake Huron are those that typically develop under oligotrophic to meso-oligotrophic conditions. Saginaw Bay, Thunder Bay, and the nearshore zones southward from these areas support populations characteristic of eutrophy. From our results, Saginaw Bay is the most adversely impacted region in the study area.

Surveillance and monitoring of Lake Huron algal assemblages on a consistent yearly and seasonal basis is recommended to remain abreast of what appears to be rapidly changing conditions. We suggest that the most effort- and cost-efficient monitoring program may consist of offshore shipboard surveillance and regular sampling at selected water intake facilities.

Analysis of phytoplankton abundances and species associations, as determined by principal component analysis, indicates that there are five major floristic regions in the study area which correspond to nutrient loading gradients. Saginaw Bay and the nearshore zone south of the bay typically supported higher cell concentrations and more eutrophication tolerant populations than any other lake region. The nearshore zone between Alpena and Tawas City also exhibited high phytoplankton standing crops and some floristic components characteristic of eutrophy. The Canadian nearshore zone had moderately high cell densities but contained species which may be found in the offshore waters or are considered eurytopic. Nearshore zones usually exhibited greatly elevated abundances compared to offshore waters of the central and southern basins. Offshore regions generally maintained low

standing crops and species characteristic of oligotrophic to meso-oligotrophic conditions. However, one region in the western central basin showed close affinities to its adjacent nearshore zone, possibly indicating affects of nearshore loading and/or slight nutrient enrichment from Saginaw Bay.

Results of principal component analysis indicate that the IJC segmentation scheme could be improved for assessing phytoplankton associations on a regional basis. Although the segmentation scheme is adequate, nearshore regions and Saginaw Bay could be further dissected for future analysis of phytoplankton assemblages.

Between 1974 and 1980, outer Saginaw Bay showed considerable decreases in total phytoplankton standing crops. Although the region exhibited substantial decreases, certain stations that were noticeably influenced by Saginaw Bay experienced order of magnitude reductions. Accompanying standing crop decreases were the reduction, or in some cases, the total elimination of populations characteristic of eutrophic or hypereutrophic conditions. Some of the species that were observed in 1974 but were absent in 1980 are classic nuisance species. The qualitative and quantitative improvements in outer Saginaw Bay are apparently due to the nutrient control measures instituted for the Saginaw River watershed.

The remainder of the study area showed elevated total phytoplankton standing crops compared to those observed during 1974. However, several oligotrophic diatom species characteristic of the offshore waters were significantly reduced in 1980. Conversely, increases were observed for phytoflagellate populations. These observations may be an indication of continued population succession in the offshore waters and may indicate slightly degrading water quality. However, this trend is difficult to

interpret due to the unsatisfactory state of knowledge concerning flagellate autecology and year-to-year fluctuations due to factors other than nutrient loadings. The Canadian nearshore zone showed modestly higher cell numbers during 1980 that were accompanied by qualitative species changes. Typically, diatom abundances were again reduced and phytoflagellate populations increased.

During 1974, eutrophic populations were observed to be transported from Saginaw Bay to the open lake in various patterns. Passive dispersal appeared to be an additional nutrient burden on the open lake. Also of concern is the transport of toxic compounds and other anthropogenic substances which are sorbed by transported phytoplankton. Distributions of algal populations and the results of principal component analysis indicated that the transport of Saginaw Bay-generated assemblages, and consequently the influence of Saginaw Bay, was not as extensive during 1980 as in 1974. Transboundary movement of Saginaw Bay algal assemblages was not detected during 1980. Algal transport undoubtedly still occurs, but the reductions in species characteristic of Saginaw Bay through nutrient abatement has minimized the transport of obnoxious algal populations. Dispersal attenuation will aid in preserving the offshore water quality of the southern basin and in meeting non-degradation objectives.

## MATERIALS AND METHODS

### STATION ARRAY

Phytoplankton samples were collected from southern Lake Huron during the ice-free months of 1980. Three cruises each were conducted aboard the CSS LIMNOS and the R/V ROGER R. SIMONS. Vessels were operated on a continuous, 24-hr basis, excepting short-term layovers due to adverse weather conditions. Cruise summaries including cruise dates, duration, vessel used, and number of samples collected are presented (Table 1).

Sampling coverage (Fig. 1) included the southern and central basins of Lake Huron and the outer Saginaw Bay region. Stations were generally occupied in numerical sequence from south to north. Sampling commenced at Port Huron, Michigan, and proceeded northward across the southern basin in a diagonal pattern. Outer Saginaw Bay and the interface region were sampled in a zig-zag pattern from south to north. Sampling in the central basin was comprised of two east-west transects terminating at Alpena, Michigan. The typical sampling sequence and sample numbers for 5-m phytoplankton collections are presented in Table 2. Additional samples were collected from master stations at various depths from stations 9 (1, 10, 15, 20, 25, 30, 50, and 57 m), 94 (1, 7, and 12 m), and 32 (1, 15, 25, 70, and 80 m). All stations were sampled for all cruises, excepting those of the two northernmost transects during the first cruise because of adverse weather conditions.

The station array covered the southern basin extremely well. A more dense sampling pattern for the open waters of the central basin may have been beneficial but the present design is satisfactory. For assessing the impact of Saginaw Bay on the open lake, sampling coverage could have been more dense for and extended deeper into Saginaw Bay. However, the Saginaw Bay-Lake Huron

TABLE 1. Summary of South Lake Huron cruise season, 1980.

Date	Vessel	Sample #	Total Slides
9 - 17 April	R/V SIMONS	1 - 64	64
10 - 13 May	R/V SIMONS	65 - 126	62
28 May - 2 June	CSS LIMNOS	127 - 184	68
18 - 22 July	R/V SIMONS	185 - 246	62
8 - 12 September	CSS LIMNOS	247 - 321	74
22 - 28 October	CSS LIMNOS	322 - 377	56

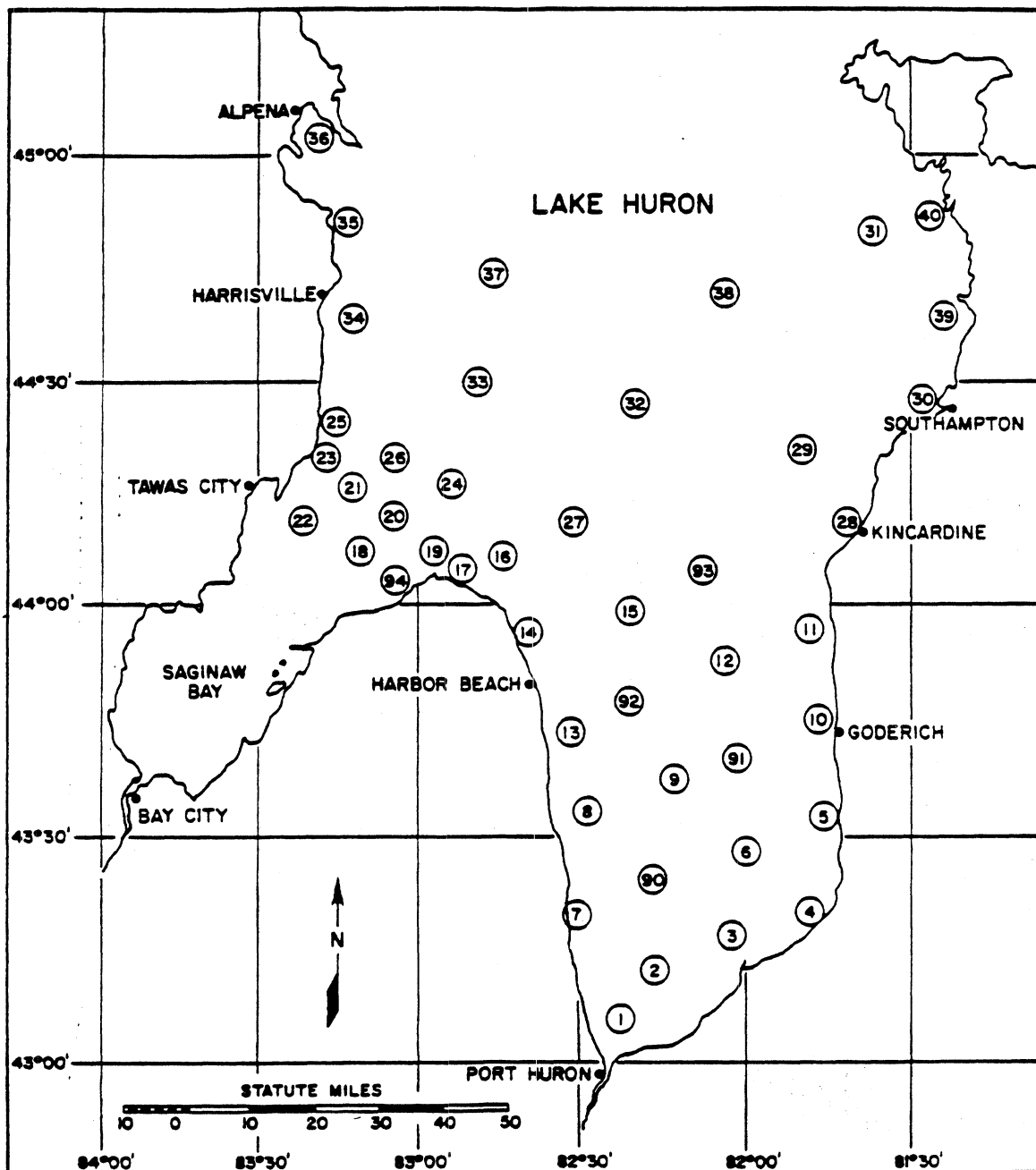


FIG. 1. Station array, southern Lake Huron, 1980 sampling season.

TABLE 2. Phytoplankton 5-meter sample/slide #'s by cruise. Station numbers are presented in the sequence stations were occupied and sample numbers are presented by cruise (1-6) for deviations in sequence.

STA #	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
01	17	65	127	185	247	322
02	18	-	128	186	248	323
03	19	68	129	187	249	324
04	20	69	130	188	250	325
05	21	70	131	189	251	326
06	22	71	132	190	252	327
90	23	72	133	191	253	328
07	24	73	134	192	254	329
08	25	74	135	193	255	330
09	27	76	137	195	257	332
91	34	83	144	205	266	335
10	35	84	145	206	267	336
11	36	85	146	207	268	337
12	37	86	147	208	269	338
92	38	87	148	209	270	339
13	39	88	149	210	271	352
14	40	89	150	211	272	351
15	41	90	151	212	273	353
93	42	91	152	213	274	354
27	43	92	153	215	275	355
16	44,16	93	154	216	276	356
17	45,15	94	155	217	277	350
24	55,13	95	167	219	290	357
19	46,14	96	156	218	278	349
94	53	98	158	221	280	341
18	49,10	101	161	223	284	343
20	57,6	102	160	224	283	348
26	58,5	103	166	225	289	358
21	59,4	104	163	226	286	347
22	47,3	105	162	227	285	344
23	60	106	164	228	287	345
25	61,1	107	165	229	288	346
34	62	126	169	230	319	375
33	-	108	168	231	291	359
32	-	110	172	233	292	361
29	-	114	182	238	311	367
28	-	115	181	214	312	368
30	-	116	180	239	313	369
39	-	117	179	240	314	370
40	-	118	178	241	315	371
31	-	119	177	242	316	372
38	-	120	176	243	317	373
37	-	121	170	244	318	374
35	63	123	183	245	320	376
36	64	125	184	246	321	377

interface had ample coverage. In general, the nearshore zones in the study area were well represented.

#### SAMPLE COLLECTION, PREPARATION, AND MICROSCOPIC ANALYSIS

Samples were collected from discrete depths by Niskin bottle casts. For the purposes of this study, samples from 5 m were chosen to represent the areal distribution and abundance of phytoplankton in the epilimnion. Whole water subsamples (125 mL) were split from 8-L Niskin bottles, fixed with glutaraldehyde (4% by volume), and refrigerated. Subsamples were stored in the dark for at least 4 hr to assure complete fixation. After gentle sample agitation for phytoplankton resuspension, a 50-mL aliquot was filtered through a 0.8  $\mu$ m, 25-mm AA Millipore filter and dehydrated by an increasing concentration ethanol series. The filter was then embedded in clove oil on a 50- X 75-mm slide and covered with a 43- X 50-mm coverglass. After filter clearing, additional mounting media was added to the slides for replacement due to volatilization. Coverglasses were ringed with paraffin to increase slide longevity.

Microscopic identification and enumeration were accomplished using a Leitz Ortholux research microscope fitted with a fluorite immersion objective (N.A. 1.32) rendering a magnification of 1,200X. Quantitative estimates were calculated from two 10-mm transect counts corrected for volume filtered, effective filtration diameter, and microscopic field width. A total of 259 5-m samples were analyzed for phytoplankton species composition and abundance. Slides are housed at the Great Lakes Research Division, The University of Michigan.

Niskin bottle subsamples were also used for physical parameters, nutrient chemistry, and chlorophyll a measurements. Complete analytical techniques and physico-chemical data can be found in Moll et al. 1985.

#### DATA REDUCTION AND PRESENTATION

Phytoplankton data were computer-formatted and read through an internal program producing output in a reduced format (Table 3). Each sample is described in terms of absolute and relative abundances of the major algal divisions and individual species. Total phytoplankton abundance, number of species observed, species diversity ( $H'$ ), evenness, and statistical error associated with quantitative estimates are also calculated.

Due to the large size of this data set, approximately 400 pages, it is not practical to include all of the data, even in the reduced form discussed above. These data are available from the authors in either hard copy or tape upon request. However, a descriptive summary for the year is provided in Appendix II. The summary includes a floristic list of taxa encountered, the number of samples in which the taxon appears, and average and maximum absolute and relative abundances for the year.

The abundance of total phytoplankton and the major algal divisions have been summarized according to the lake segmentation scheme developed by the International Joint Commission (1977). The IJC segmentation scheme is presented in Figure 2. Since Saginaw Bay has a unique species composition and usually maintains high algal standing crops, we have added an additional segment, designated as 7a, on Figure 2. The IJC segmentation scheme is overlain on the 1980 southern Lake Huron station array in Figure 3 and the station numbers are grouped by segment in Table 4.

TABLE 3. Computer-reduced phytoplankton data format.

SLH South Lake Huron 05 September 1980					
project:	SLH	survey number:	5		
year:	1980	Julian day:	253 ( 9 Sep)		
station:	15	depth:	5.0 m		
latitude:	44° 00.0'	longitude:	82° 21.0'		
number of cells counted:	1329	volume of water scanned:	0.477 ml		
diversity:	1.853	evenness:	0.540		

division	number of species	cells/ml	SE	CV	% pop.
Cyanophyta (blue-green algae) . . .	3	1734.2	188.5	0.11	62.302
Chlorophyta (green algae) . . .	7	140.3	60.7	0.43	5.041
Bacillariophyta (diatoms) . . .	4	261.8	6.3	0.02	9.406
Chrysophyta (chrysophytes) . . .	7	345.6	232.5	0.67	12.415
Cryptophyta (cryptomonads) . . .	6	106.8	2.1	0.02	3.837
Pyrrophyta (dinoflagellates) . . .	3	8.4	0.0	0.0	0.301
other . . .	0	0.0	0.0	****	0.0
undetermined . . .	1	186.4	18.8	0.10	6.697
total	31	2783.4	337.2	0.12	100.000

species name	cells/ml	SE	CV	% pop.
Anacystis incerta . . .	1397.0	77.5	0.06	50.188
Chrysosphaerella longispina . . .	291.1	261.8	0.90	10.459
Gomphosphaeria lacustris . . .	259.7	259.7	1.00	9.330
Cyclotella comensis . . .	245.0	6.3	0.03	8.804
Undetermined flagellate spp. . .	186.4	18.8	0.10	6.697
Anacystis thermalis . . .	77.5	6.3	0.08	2.784
Botryococcus braunii . . .	73.3	73.3	1.00	2.634
Rhodomonas minuta var. nannoplanctica . . .	56.5	2.1	0.04	2.032
Dinobryon divergens . . .	37.7	29.3	0.78	1.354
Gloeocystis planctonica . . .	27.2	27.2	1.00	0.978
Rhodomonas minuta . . .	20.9	4.2	0.20	0.752
Chroomonas spp. . .	14.7	10.5	0.71	0.527
Oocystis spp. . .	14.7	2.1	0.14	0.527
Cryptomonas spp. . .	8.4	4.2	0.50	0.301
Cyclotella pseudostelligera . . .	8.4	8.4	1.00	0.301
Eutetramorus spp. . .	8.4	8.4	1.00	0.301
Lagerheimia ciliata . . .	8.4	8.4	1.00	0.301
Monochrysis aphanaster . . .	6.3	2.1	0.33	0.226
Cosmarium botrytis . . .	4.2	4.2	1.00	0.150
Cryptomonas ovata . . .	4.2	0.0	0.0	0.150
Cyclotella comta . . .	4.2	4.2	1.00	0.150
Cyclotella michiganiana . . .	4.2	4.2	1.00	0.150
Undetermined green individual . . .	4.2	4.2	1.00	0.150
Mallomonas pseudocoronata . . .	4.2	0.0	0.0	0.150
Spirodinium pusillum var. minor? . . .	4.2	4.2	1.00	0.150
Ceratium hirundinella . . .	2.1	2.1	1.00	0.075
Chrysococcus dokidophorus . . .	2.1	2.1	1.00	0.075
Gymnodinium spp. . .	2.1	2.1	1.00	0.075
Chroomonas nordsetdii . . .	2.1	2.1	1.00	0.075
Chrysophycean flagellate spp. . .	2.1	2.1	1.00	0.075
Ochromonas spp. . .	2.1	2.1	1.00	0.075

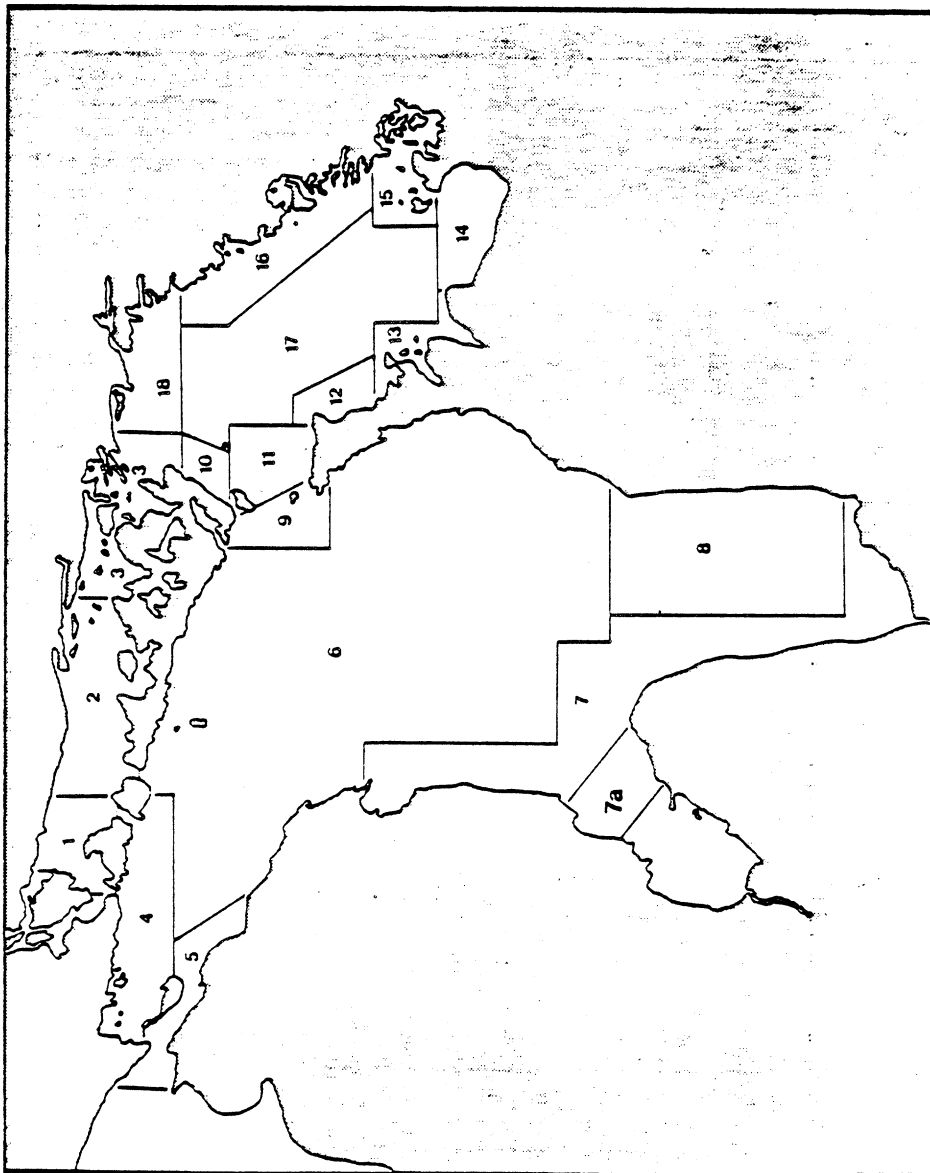


FIG. 2. Segmentation scheme developed by the International Joint Commission.

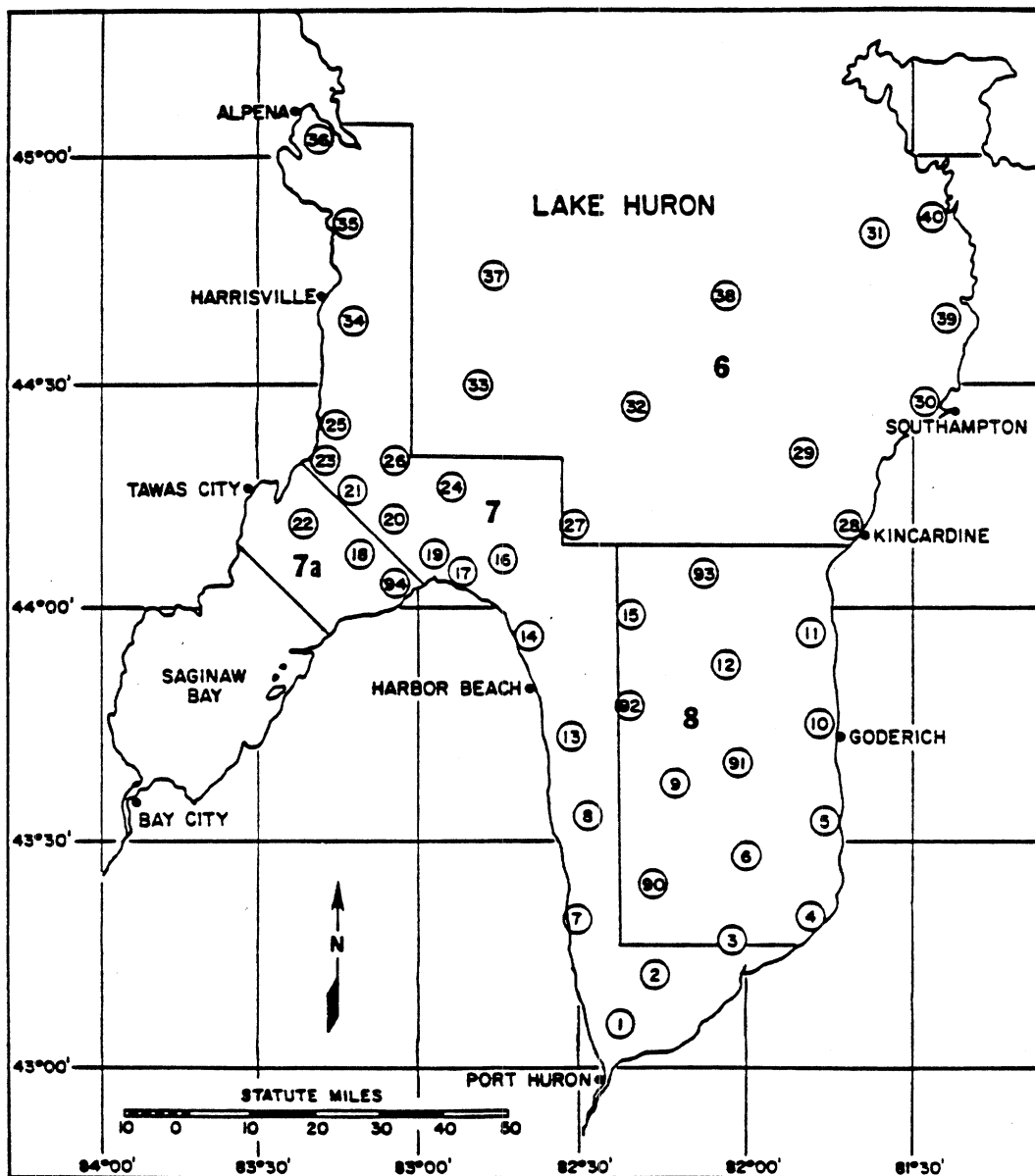


FIG. 3. Southern Lake Huron sampling array in the IJC segmentation scheme.

TABLE 4. Southern Lake Huron sampling stations, 1980, grouped according to the IJC segmentation scheme.

7a	7	8	6
18	1	3	27
22	2	4	28
94	7	5	29
	8	6	30
	13	9	31
	14	10	32
	16	11	33
	17	12	37
	19	15	38
	20	90	39
	21	91	40
	23	92	
	24	93	
	25		
	26		
	34		
	35		
	36		
n = 3	18	13	11

## RESULTS

### SURVEY-WIDE AVERAGES

The overall abundance of phytoplankton at all stations sampled through all cruises during 1980 is presented in Table 5. Total average phytoplankton abundance in southern Lake Huron was moderate in 1980, with a range encompassing one order of magnitude. Of the major physiological groups observed, diatoms were the most abundant in southern Lake Huron, comprising 35% of the assemblage. Blue-green algae and an undetermined category were the two next most abundant groups. Chrysophytes and cryptomonads, both flagellate groups, were common in the study area. Green algae, on average, were a minor component of planktonic assemblages. Dinoflagellates and euglenoids represented a very small fraction of the algal flora.

The undetermined category is primarily composed of microflagellates which cannot be satisfactorily assigned to divisional groups using light microscopic techniques. Many flagellate forms are not well known for or have only recently been reported from the Great Lakes. These flagellates can best be characterized as nanoplankton or picoplankton, ranging in size from 0.2 to 5.0  $\mu\text{m}$  in diameter. After further research, the bulk of microflagellates may be aligned with the Haptophyta, Chloromonadophyta, Chrysophyta, and Prasinophyta (Munawar and Munawar 1975, Stoermer and Sicko-Goad 1977, Nicholls et al. 1977a). Microflagellates are common throughout all of the major algal divisions, excepting the diatoms and blue-greens. When all phytoflagellates are considered collectively, they constitute a substantial portion of planktonic assemblages observed.

TABLE 5. Summary of southern Lake Huron phytoplankton for all cruises (1-6) at 5 meters, 1980.

Average (cells/mL)	1881.2
Range (cells/mL)	222.0 - 6272.7
Standard deviation	997.3
Mean diversity	2.389

	*Ave. Relative Abundance (%)	Ave. Absolute Abundance (cells/mL)
Blue-greens	18.85	413.63
Greens	5.41	96.67
Diatoms	35.52	649.02
Chrysophytes	11.12	200.15
Cryptomonads	8.78	141.75
Dinoflagellates	.33	5.36
Euglenoids	<.01	.01
Undetermined	19.94	373.41

\*Average relative abundance, as presented here, is calculated by dividing the sum of assemblage percentages by the total number of samples. Relative abundance can also be calculated from the values presented by dividing the average absolute abundance by the average total abundance. Differences between the two calculation methods are negligible in this data set.

## SEASONAL AVERAGES OF TOTAL PHYTOPLANKTON AND THE MAJOR ALGAL GROUPS

Seasonal trends of total phytoplankton are presented in Table 6 and Figure 4. Total algal abundance in southern Lake Huron exhibited a bimodal pattern in 1980 (Fig. 4). Highest total standing crop was observed in April with slightly lower abundances in September and October. A summer minimum was observed in July where the lowest standing crop for the sampling season was recorded.

Mean seasonal values for the major algal divisions are presented in Table 6 and Figures 5 and 6. Diatoms showed fairly consistent values through all seasons with the highest abundance recorded in October and lowest in September. Blue-green algae showed greatest cell concentrations and dominated in September and October. The largest green algal standing crop was observed in September, although most mean values were uniform through the sampling season. Chrysophytes reached their highest densities during the spring in April and May and were observed in lowest abundance in July. Cryptomonads showed seasonal consistency through the sampling period but were most abundant in May, with lowest values recorded for July. Dinoflagellate standing crop was comparatively low, with their greatest abundance recorded in June. Euglenoids were virtually absent from the study area. The undetermined category (primarily microflagellates) was dominant during April with decreasing values through the remainder of the year.

## SEGMENT AVERAGES

In order to inspect regional differences in total and divisional algal abundance, mean values are presented according to the IJC segmentation scheme.

TABLE 6. Seasonal means of southern Lake Huron total phytoplankton and major algal groups (cells/mL) for cruises 1-6 at 5 meters, 1980.

GROUP	CRUISE					
	1	2	3	4	5	6
Total	2,400.2	1,905.7	1,639.7	1,100.2	2,190.4	2,166.7
Blue-greens	177.5	150.6	202.6	21.7	994.2	876.9
Greens	72.4	112.0	88.5	73.4	123.6	105.1
Diatoms	696.4	596.0	651.9	621.9	585.1	752.3
Chrysophytes	363.9	336.3	168.1	52.0	159.2	160.9
Cryptomonads	151.2	266.3	164.2	83.3	89.5	101.0
Euglenoids	0.0	0.0	0.0	0.0	0.1	0.0
Dinoflagellates	3.0	5.2	8.9	5.3	7.0	2.2
Undetermined	930.4	437.2	355.4	242.6	231.8	168.3

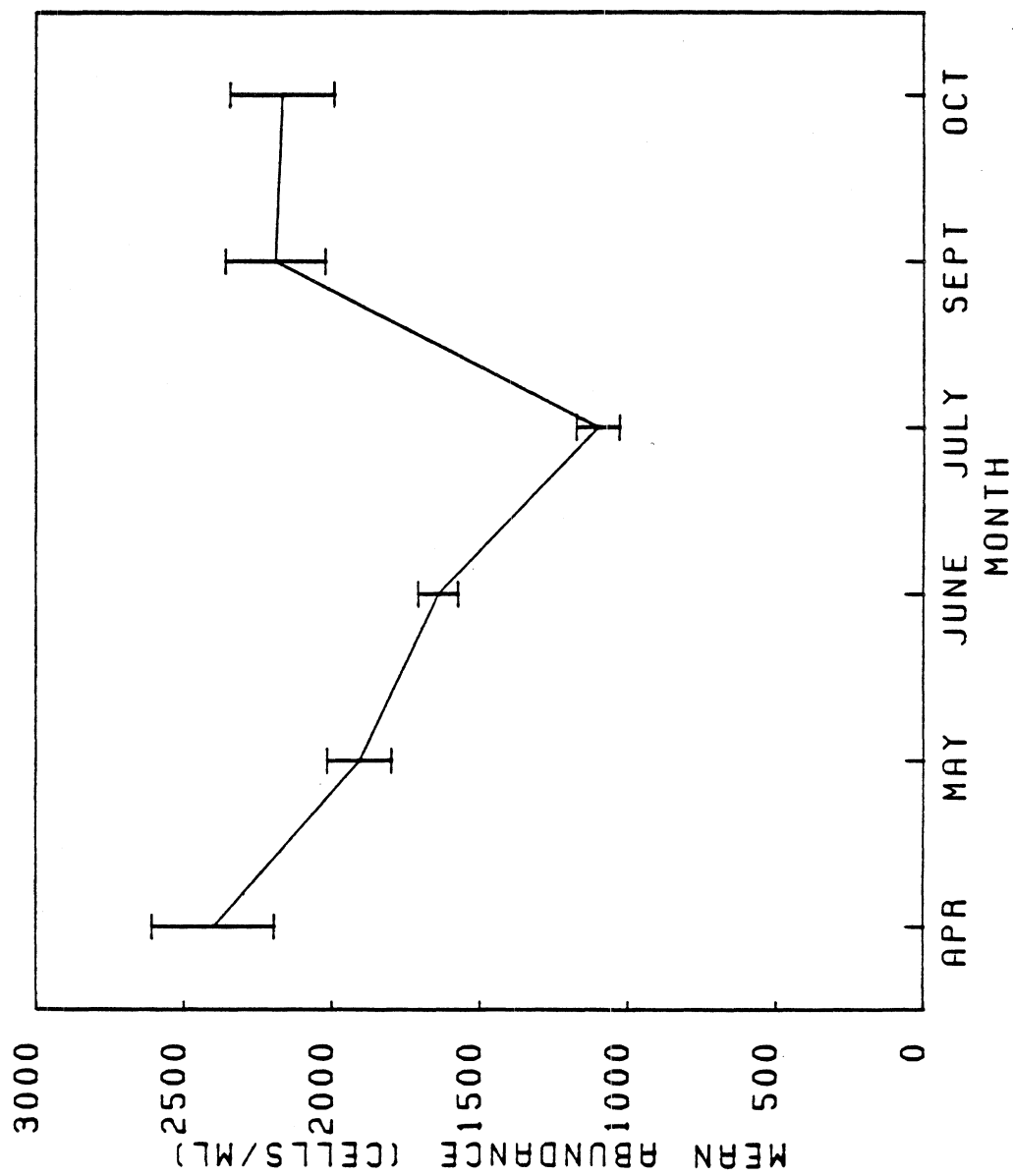


FIG. 4. Mean southern Lake Huron phytoplankton abundance (cells/mL) at 5 meters for cruises 1-6, 1980. Error bars =  $\pm$  standard error.

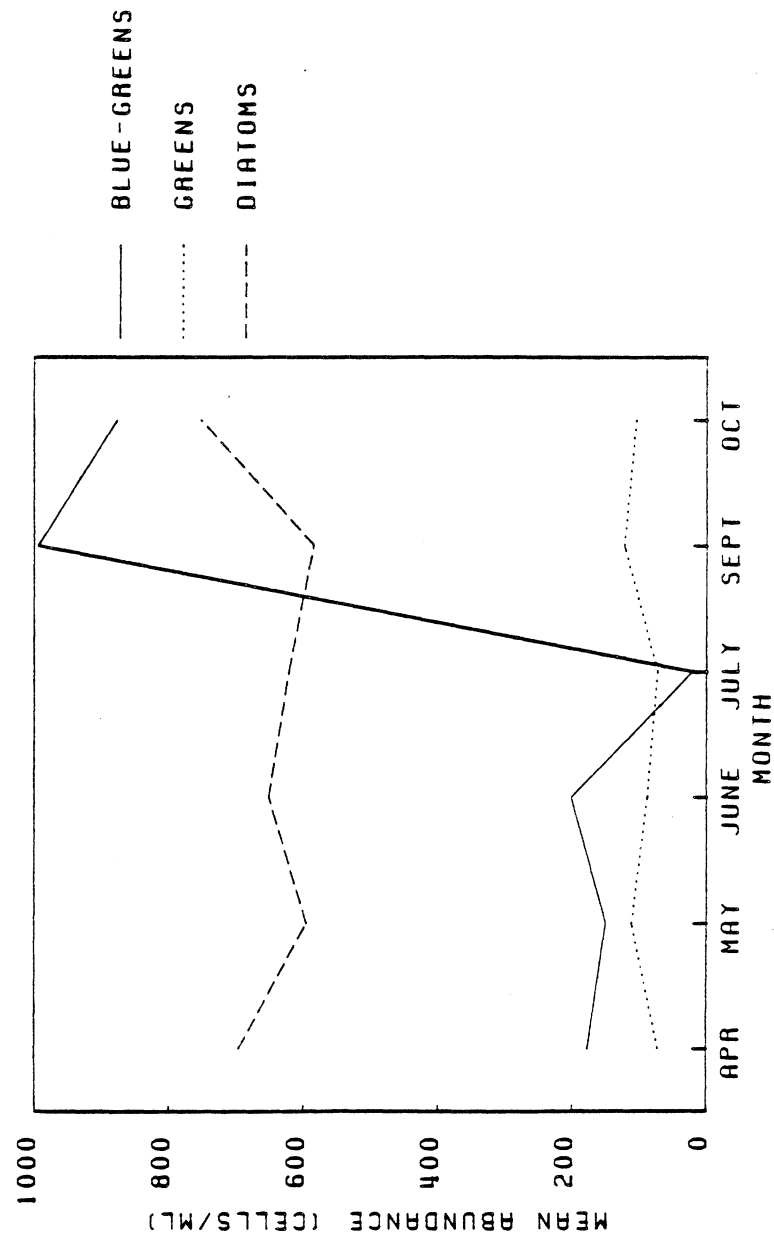


FIG. 5. Mean abundance (cells/mL) of blue-greens, greens, and diatoms at 5 meters for cruises 1-6, 1980.

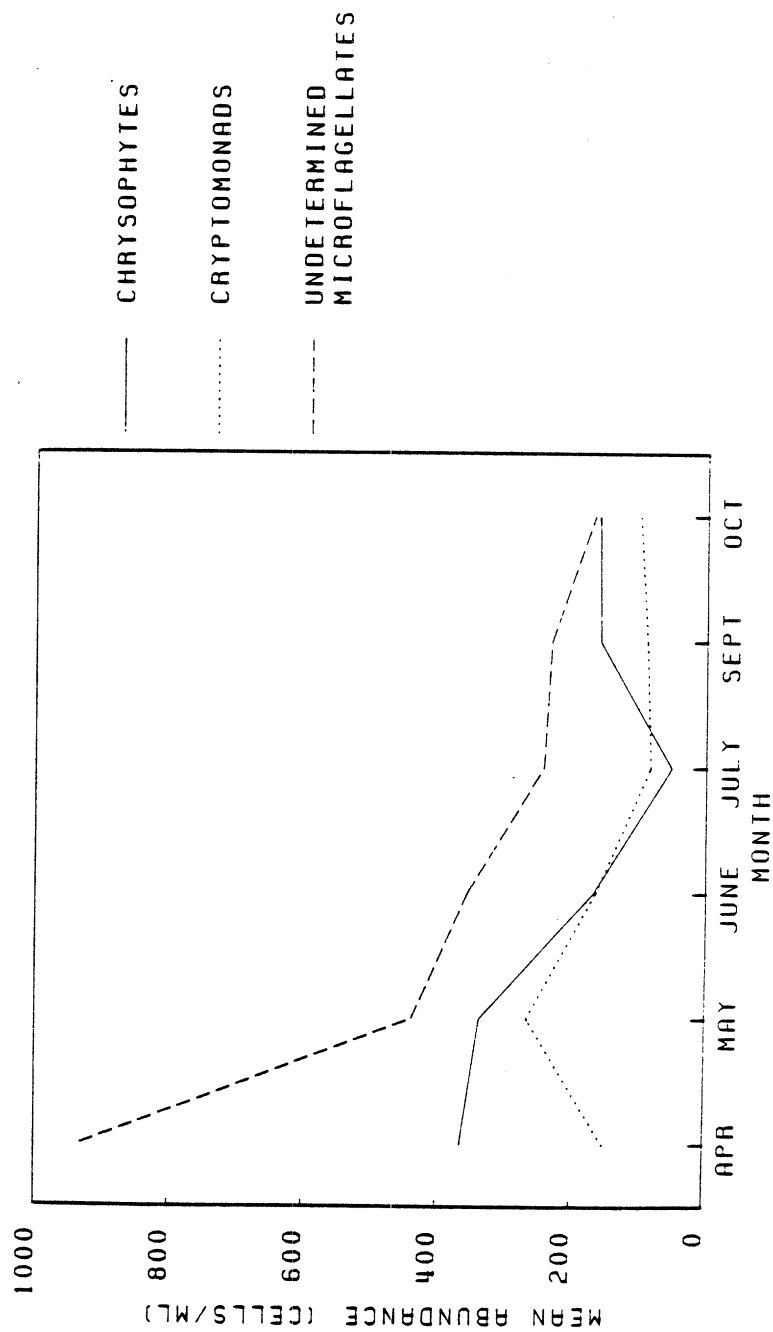


FIG. 6. Mean abundance (cells/mL) of chrysophytes, cryptomonads, and undetermined microflagellates at 5 meters for cruises 1-6, 1980.

Mean phytoplankton abundance by segment for each cruise is presented in Table 7. Segment 7a exhibited the highest average abundance during 1980 and generally had the highest individual cruise values. Segment 7 had slightly lower, but similar abundance values in comparison to segment 7a. Segments 6 and 8 showed considerably lower mean cell numbers compared to the other two segments. Segment 6 usually exhibited the lowest mean values for the study area.

Mean absolute and relative abundances of algal divisions are given in Tables 8 and 9, respectively. Highest mean absolute abundances of green algae, diatoms, and chrysophytes were recorded for segment 7a. Blue-greens and the undetermined category exhibited highest cell concentrations in segment 7. Highest mean absolute abundances of cryptomonads and dinoflagellates were recorded for segment 8 but both groups had evenly distributed densities throughout all segments. Diatoms were the dominant group in all segments.

Relative abundances of green algae and diatoms were highest in segment 7a. However, chrysophyte relative abundance was lowest in segment 7a and highest in segment 8. Greatest relative abundances of blue-greens and cryptomonads were found in segment 6. Highest relative abundance of the undetermined category was noted in segment 7.

The seasonal trends of total phytoplankton for each segment are shown in Figure 7. All four segments show bimodal patterns in total abundance. Highest standing crops were recorded during the spring or fall. Segment 6 had the lowest mean seasonal abundance and is marked by a weakly developed seasonal pattern. Cell numbers gradually increased through June and then markedly decreased in July. Abundance was highest for the year in September with decreasing values in October. Segment 8 had slightly greater abundance

TABLE 7. Mean phytoplankton abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE						Yearly Mean
	1	2	3	4	5	6	
6	1,309.0	1,393.2	1,565.1	921.1	1,627.7	1,259.9	1,352.6
7a	3,000.6	2,594.3	1,891.2	1,237.8	2,801.6	3,619.1	2,524.1
7	3,024.7	2,003.0	1,726.9	1,409.5	2,785.4	2,830.9	2,299.5
8	1,481.1	2,053.2	1,524.1	791.5	1,701.8	1,679.2	1,538.3

TABLE 8. Mean absolute abundance (cells/mL) of algal divisions in southern Lake Huron by segment for all cruises (1-6) at 5 meters, 1980.

SEGMENT	GROUP					
	BLUE-GREENS	GREENS	DIATOMS	CHRYSOPHYTES	CRYPTOMONADS	DINOFLLAGELLATES
6	331.06	80.41	398.61	154.54	141.18	4.00
7a	453.55	153.94	1,139.70	238.99	131.48	5.70
7	503.95	102.86	805.42	223.32	130.48	5.70
8	339.80	86.65	501.10	192.17	160.01	5.80
						242.80
						400.73
						526.65
						250.68



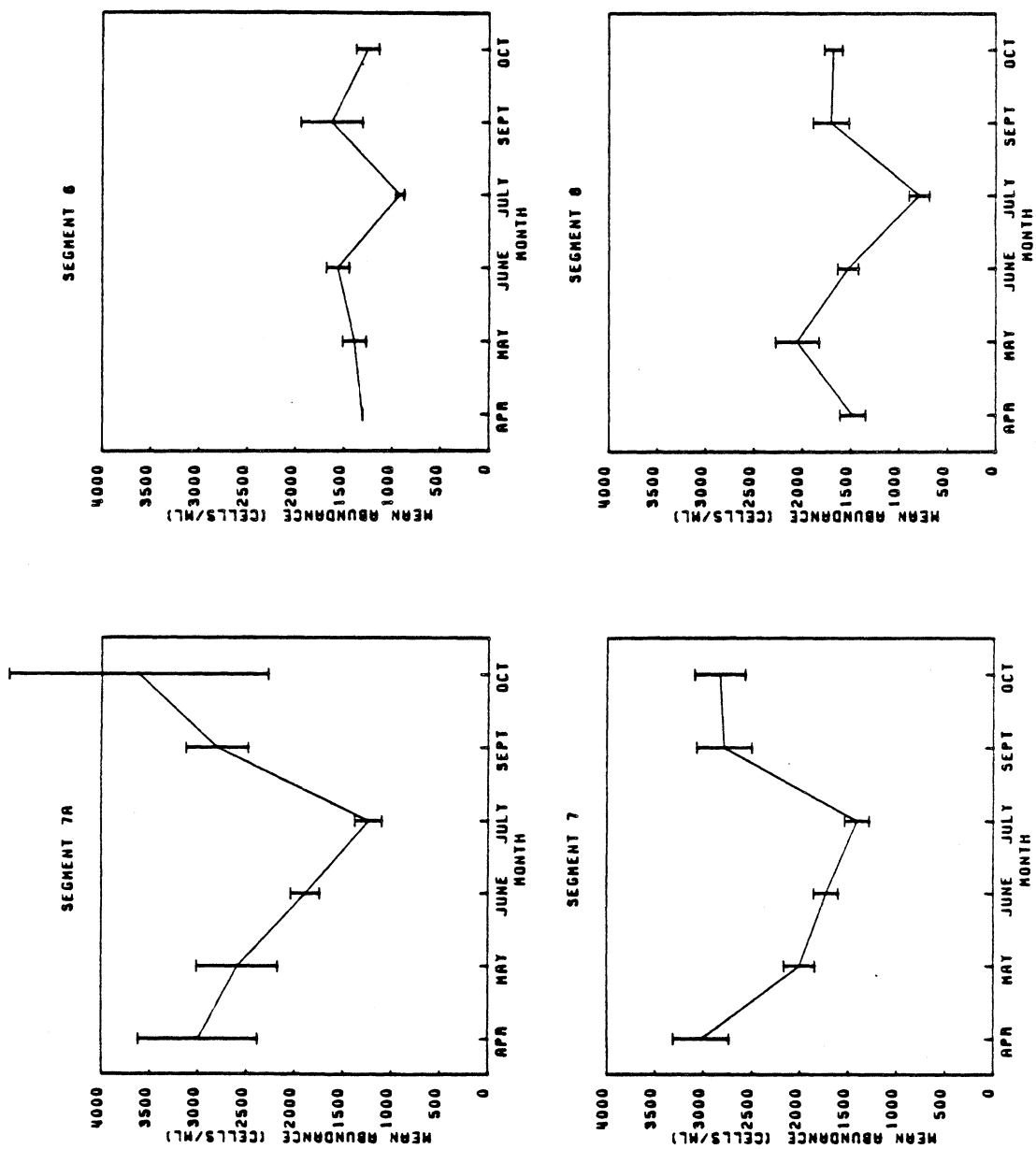


FIG. 7. Seasonal trends (cells/mL) of total phytoplankton by segment, 1980. Error bars =  $\pm$  standard error.

than segment 6. Standing crop increased from April to May, reaching segment 8's highest mean abundance for the year. Abundance decreased through June to a summer minimum in July. Mean abundance rose in September with a comparable mean value for October. Segment 7 generally had higher mean values than either segment 6 or 8. Highest mean cell densities for the year were seen in April. Consecutively less abundance was seen through May and June and then during the summer minimum in July. Much higher values were observed for September and October. Segment 7a had the highest average standing crop of all segments. Its seasonal trend resembled segment 7. High mean values were seen in April with decreasing values to the lowest mean in July. Large fall values were seen in September, attaining the highest mean abundance for this segment in October.

Seasonal trends of the major physiological groups by segment are presented in Figure 8. The physiological groups in segment 6 showed little seasonal periodicity except for blue-greens. Total flagellates dominated and diatoms subdominated until September and October when blue-greens became dominant. In segment 8, total flagellates were the most abundant in April and May. Diatoms and flagellates were both abundant in June, with diatoms dominating in July. Blue-greens were in greatest concentrations in September and October. For segment 7, very large concentrations of total flagellates were observed in April and May. Total flagellates were slightly more abundant than diatoms in June, with diatoms increasing to dominate in July. Blue-green algae increased to dominate in September and co-dominated with diatoms in October. For segment 7a, total flagellates were highest in April and May, with diatoms dominating for the remainder of the season. Blue-greens were subdominant in September and October.

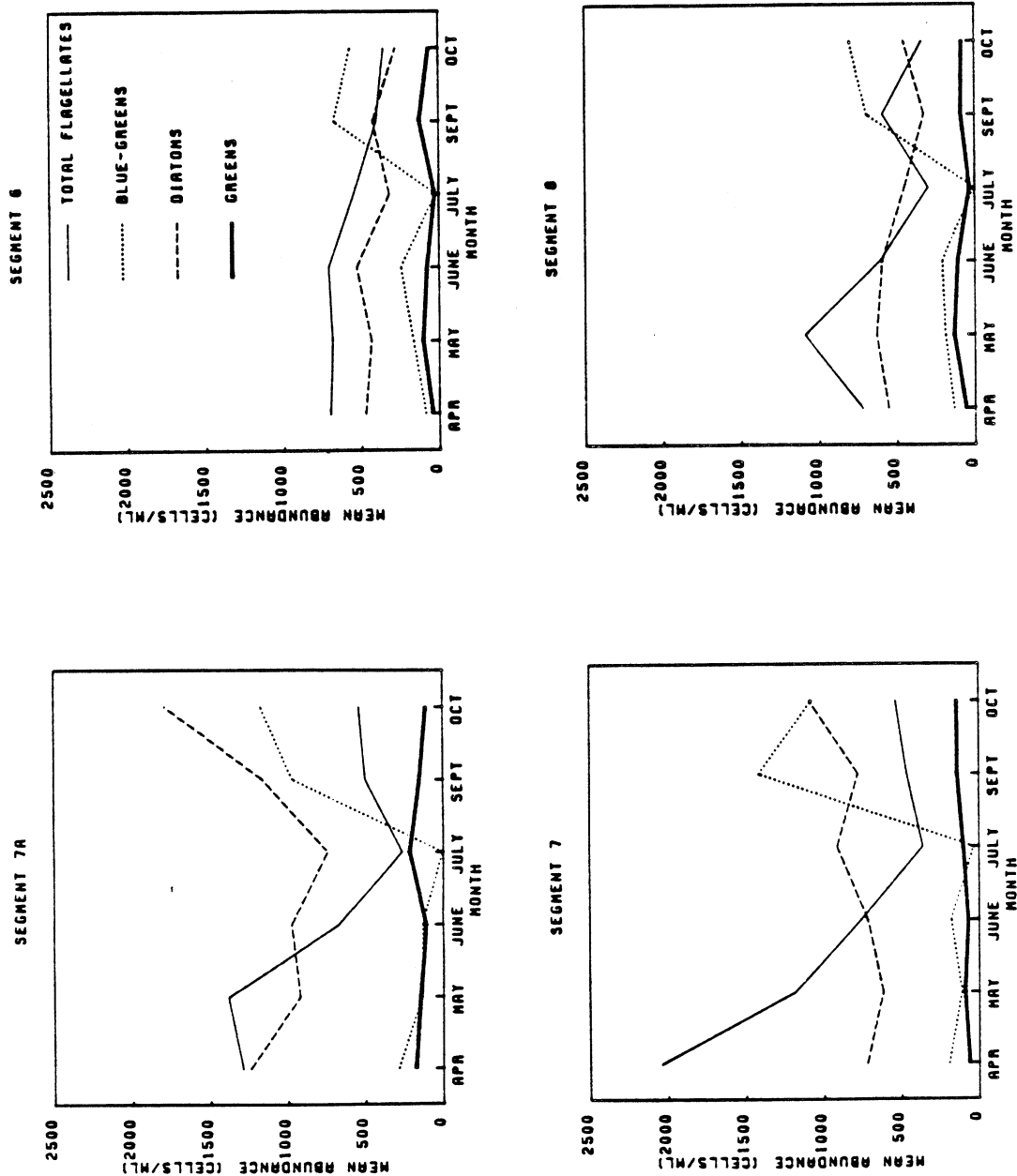


FIG. 8. Seasonal trends (cells/mL) of the major algal groups by segment, 1980.

Mean assemblage diversities by segment are presented in Table 10. Highest yearly averages were seen in segments 6 and 8; however, the mean values for all segments are fairly similar. Large fluctuations in diversity were seen in all segments, with highest diversities generally recorded for the spring and lowest in the summer.

Mean absolute abundances of the major algal groups by segment and cruise are given in Tables 11-17. For comparative purposes, mean relative abundances for these groups are presented in Tables 18-24 by segment and cruise.

#### THE PHYTOPLANKTON FLORA OF SOUTHERN LAKE HURON

A summary of the algal species encountered in southern Lake Huron during this study is presented in Appendix II. Taxa are arranged by divisional group, then alphabetically by genus and species. Also given are the average absolute and relative abundances, and the maximum absolute and relative abundances.

In a number of cases, complete taxonomic identification could not be accomplished. These entities were identified to the lowest taxonomic level possible and assigned a number. Identification of these entities could not be accomplished because of poor microscopic views, the lack of critical morphological structures for taxonomic placement, occurrence of only a few rare specimens, or because populations possessed a great deal of variability.

#### REGIONAL AND SEASONAL TRENDS IN TOTAL CELL DENSITIES

Computer-generated distribution and abundance plots are presented for total phytoplankton, the major algal groups, and individual species. Abundance bars, representing cells/mL, are given for each station sampled.

TABLE 10. Mean assemblage diversity in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE						Yearly Mean
	1	2	3	4	5	6	
6	2.726	2.896	2.792	1.997	2.188	2.444	2.468
7a	3.041	2.719	2.752	1.720	2.099	2.078	2.401
7	2.458	2.641	2.652	1.770	1.963	2.399	2.311
8	2.901	2.829	2.842	1.691	2.088	2.267	2.436

TABLE 11. Mean diatom abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	475.43	436.21	528.74	320.25	424.97	275.89
7a	1,241.30	922.93	974.59	744.21	1,166.60	1,788.60
7	720.12	616.12	715.82	910.71	773.30	1,085.90
8	554.85	629.61	593.20	449.01	325.76	454.16

TABLE 12. Mean abundance (cells/mL) of green algae in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	43.98	104.72	80.16	29.51	126.04	64.93
7a	179.42	148.70	111.30	218.52	154.99	111.70
7	64.46	92.65	72.72	102.86	140.67	143.23
8	60.90	134.85	112.29	36.41	90.54	84.90

TABLE 13. Mean blue-green algal abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	87.97	166.98	246.57	23.04	674.01	566.82
7a	288.30	138.93	134.04	7.68	975.29	1,177.00
7	193.73	112.48	181.75	34.21	1,409.80	1,070.00
8	136.30	189.30	209.92	6.44	694.21	802.64

TABLE 14. Mean chrysophyte abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	265.99	264.46	185.07	71.78	99.96	141.28
7a	365.82	497.07	108.91	52.36	166.85	242.95
7	396.19	397.20	164.76	59.69	127.53	204.20
8	326.24	280.33	172.06	24.49	251.33	98.60

TABLE 15. Mean cryptomonad abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	117.29	181.83	196.30	121.67	106.62	101.67
7a	148.70	321.84	140.32	31.42	59.34	87.27
7	154.64	240.49	148.82	57.36	81.91	105.77
8	149.51	358.62	163.68	98.60	92.48	97.15

TABLE 16. Mean dinoflagellate abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	2.09	2.86	9.33	2.67	4.19	1.14
7a	6.28	4.19	9.08	5.59	7.68	1.40
7	2.44	5.79	8.73	6.40	8.26	2.56
8	3.06	6.77	8.86	5.80	7.57	2.74

TABLE 17. Mean total flagellate abundance (cells/mL) in southern Lake Huron by segment for cruises 1-6 at 5 meters in 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	701.62	685.25	709.62	548.35	402.69	352.24
7a	1,291.50	1,383.70	672.30	267.38	504.75	541.75
7	2,039.80	1,181.70	756.66	361.75	461.70	531.74
8	723.21	1,092.5	607.86	299.66	591.26	337.52

TABLE 18. Mean relative abundance (%) of diatoms in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	20.32	19.98	11.83	34.77	26.11	21.90
7a	41.37	35.58	51.53	60.12	41.64	49.42
7	23.81	30.76	41.45	64.61	27.76	38.36
8	37.46	30.67	38.92	56.73	19.14	27.05

TABLE 19. Mean relative abundance (%) of green algae in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	3.36	7.52	5.12	3.20	7.74	5.15
7a	5.98	5.73	5.83	17.65	5.53	3.09
7	2.13	4.63	4.21	7.30	5.05	5.06
8	4.11	6.57	7.37	4.60	5.32	5.06

TABLE 20. Mean relative abundance (%) of blue-green algae in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	6.72	11.99	15.75	2.50	41.41	44.99
7a	9.61	5.36	7.09	0.62	34.81	32.52
7	6.41	5.62	10.52	2.43	50.61	37.80
8	9.20	9.22	13.77	0.81	40.80	47.80

TABLE 21. Mean relative abundance (%) of chrysophytes in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	20.32	18.98	11.83	7.79	6.14	11.21
7a	12.19	19.16	5.76	4.23	5.96	6.71
7	13.10	19.83	9.54	4.24	4.58	7.21
8	22.03	13.65	11.24	3.09	14.77	5.87

TABLE 22. Mean relative abundance (%) of cryptomonads in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	8.96	13.05	12.54	13.21	6.55	8.07
7a	4.96	12.41	7.42	2.54	2.12	2.41
7	5.11	12.01	8.62	4.07	2.94	3.74
8	10.10	17.47	10.74	12.46	5.43	5.79

TABLE 23. Mean relative abundance (%) of dinoflagellates in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	.16	.21	.60	.29	.26	.09
7a	.21	.16	.48	.45	.27	.04
7	.08	.29	.51	.45	.29	.09
8	.21	.33	.58	.73	.45	.16

TABLE 24. Mean relative abundance (%) of total flagellates in southern Lake Huron by segment for cruises 1-6 at 5 meters, 1980.

SEGMENT	CRUISE					
	1	2	3	4	5	6
6	53.60	49.19	45.34	59.53	24.74	27.96
7a	43.04	53.38	35.55	21.60	18.02	14.97
7	67.44	59.00	43.82	25.67	16.58	18.78
8	48.83	53.21	39.88	37.86	34.74	20.10

Highest mean standing crop values for the sampling season were recorded in April. During this month (Fig. 9A), greatest cell numbers were observed in the nearshore zone between Alpena and Tawas City. High abundances were also observed in outer Saginaw Bay and north of the Saginaw Bay interface. Moderate abundances were generally recorded for the southern basin. In May (Fig. 9B), largest cell densities were observed in the nearshore zones around the study area and in outer Saginaw Bay. Moderate abundances were observed in the offshore waters of the southern basin and comparatively less in the central basin. Uniform abundances were observed in June (Fig. 9C). The greatest cell numbers were recorded in Thunder Bay at Alpena and slightly elevated abundances were found in the Canadian nearshore zone. During July, cell numbers decreased with highest abundances in the Saginaw Bay interface and southward (Fig. 9D). Low abundances were observed in both the central and southern basins. In September (Fig. 9E), cell densities increased over July with highest cell numbers occurring in the littoral zone between Alpena and Tawas City. Some high values were also observed adjacent to Saginaw Bay. Moderate standing crop was seen in the southern basin with comparatively less abundance in the north-east sector of the central basin. Abundance in October was similar to the previous sampling period (Fig. 9F). Highest standing crops were observed in outer Saginaw Bay and adjacent waters and the nearshore zone southward. Large abundances were again recorded in the nearshore area between Alpena and Tawas City. Moderate abundances were observed in the southern offshore zone with lower cell densities observed in the mid-central basin and along the entire Canadian shoreline.

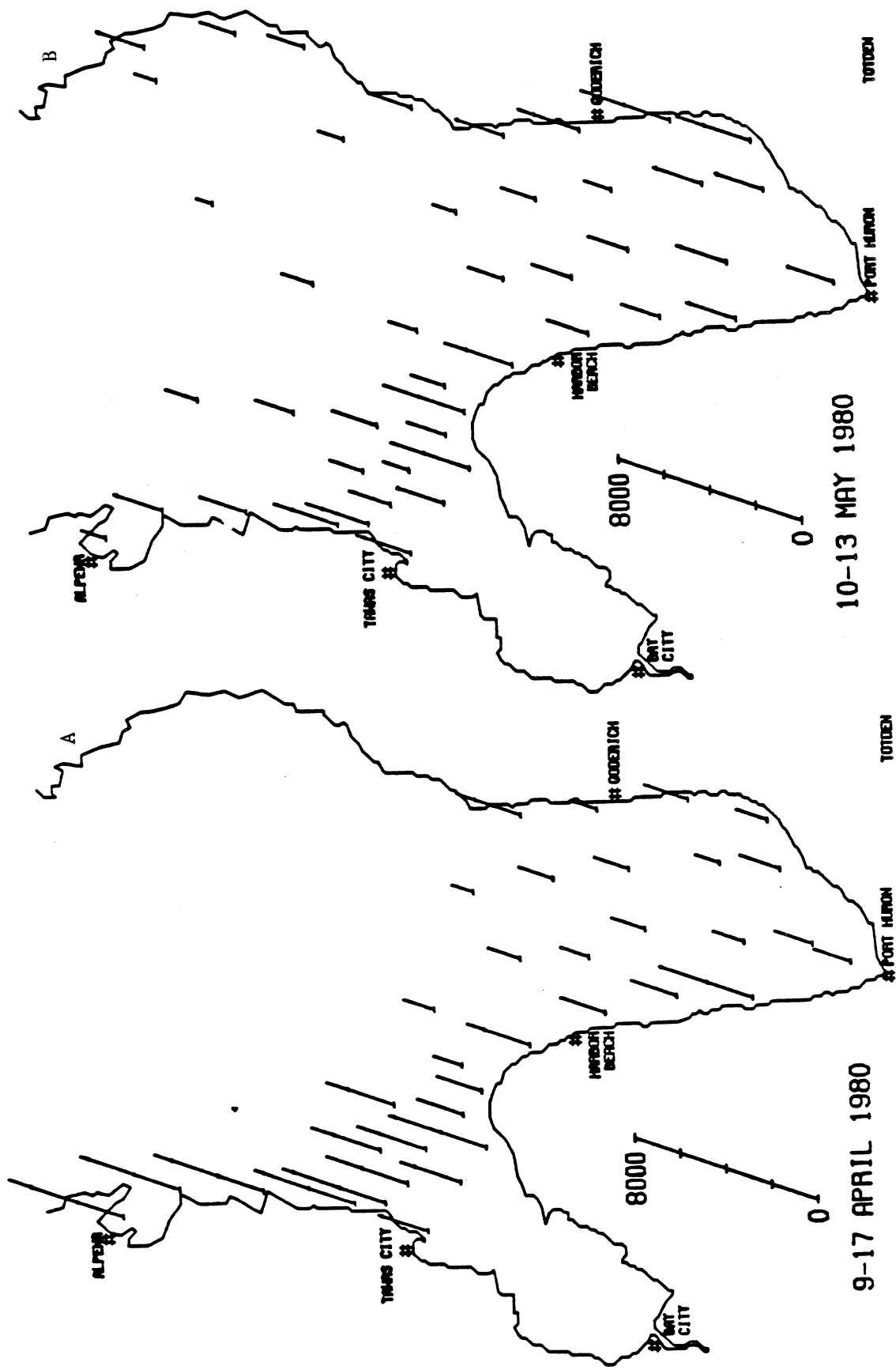


FIG. 9. Seasonal distribution and abundance trends (cells/mL) of total phytoplankton cell densities, 1980.

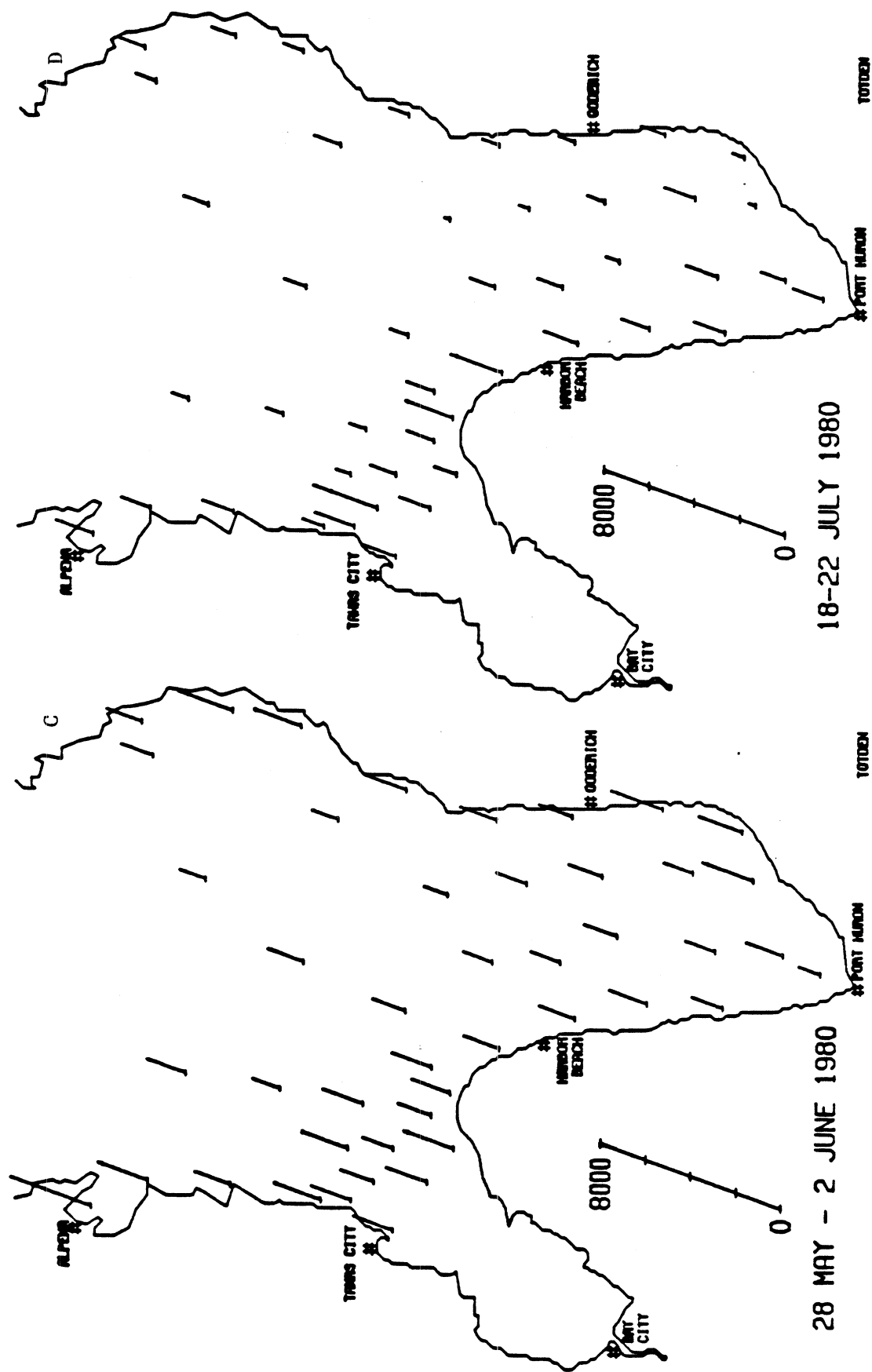


FIG. 9. (continued)

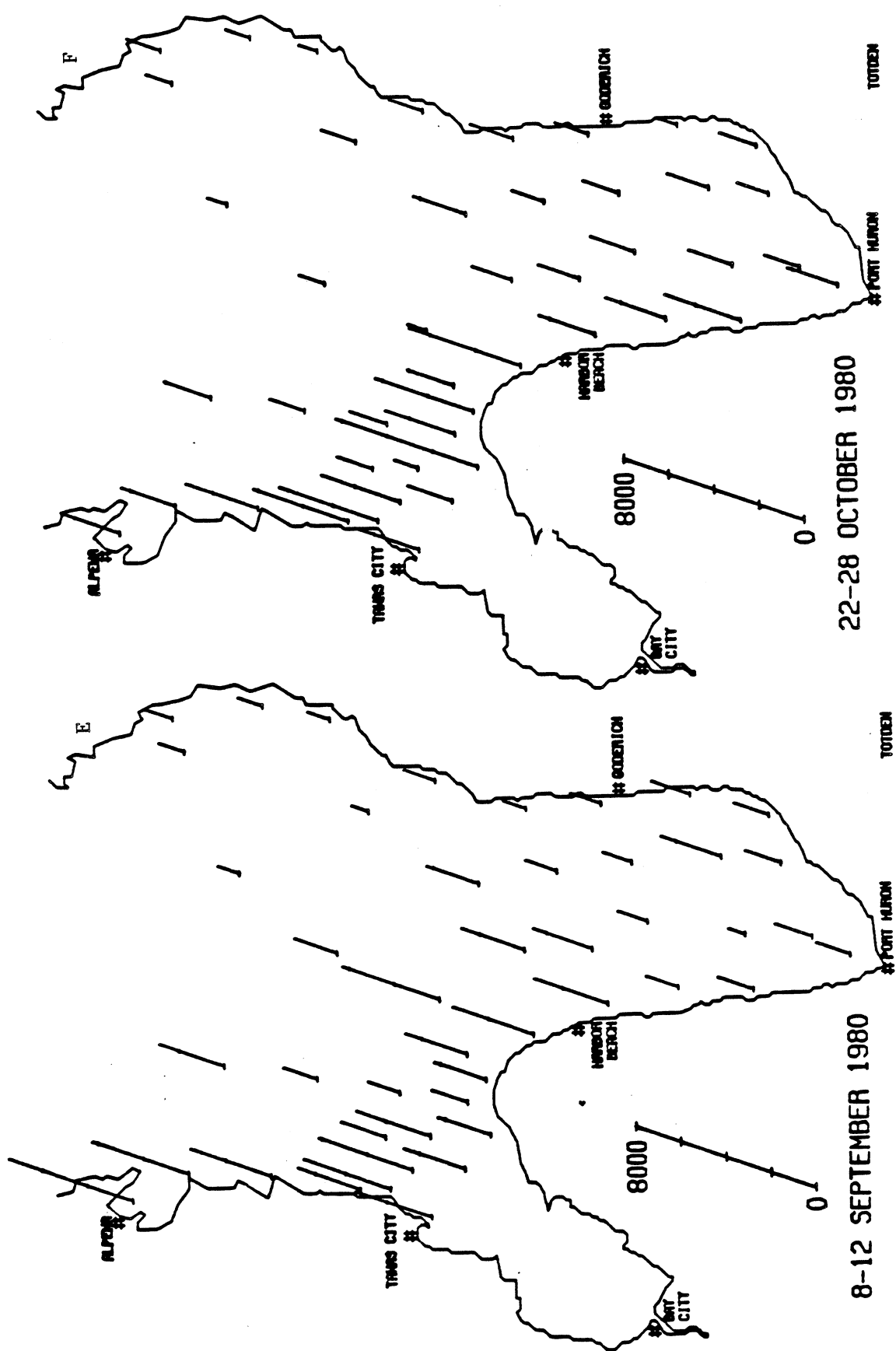


FIG. 9. (continued)

## REGIONAL AND SEASONAL TRENDS OF THE MAJOR ALGAL GROUPS AND SELECTED TAXA

### Bacillariophyta - Diatoms

Diatoms comprise a large portion of algal assemblages in the Great Lakes. During this study they accounted for 35% of the assemblages in southern Lake Huron. They have been studied extensively in the Great Lakes due to their numerical importance in assemblages and for use as indicators of trophic status. Although diatoms collectively show a wide range of tolerance over the trophic range found in the Great Lakes, individual species show apparent preferences to particular environmental conditions.

In April (Fig. 10A), diatom abundance was greatest at a station in the south-east corner of Saginaw Bay. High values were also seen in the nearshore zone between Saginaw Bay and Port Huron. Relatively uniform cell densities were observed over the remainder of the study area sampled. Highest abundances in May (Fig. 10B) were again observed in nearshore zones, possibly in response to spring thermal bar conditions. Greatest abundances were recorded in outer Saginaw Bay and around the thumb area. High values were also observed nearshore south of Goderich and south of Thunder Bay. The offshore waters of the southern and central basins showed relatively low, uniform cell densities. During June (Fig. 10C), moderate, uniform abundances were seen over the entire study area with only slightly elevated cell numbers recorded for nearshore zones. During July (Fig. 10D), highest abundances were seen in the U.S. sector of the lake, particularly in nearshore areas but extending slightly into offshore waters. Comparatively lower abundance was seen in the Canadian sector and very low values were recorded for the open waters of the central basin. Very low diatom cell numbers were observed over most of the study area in September (Fig. 10E). On average, diatom abundance

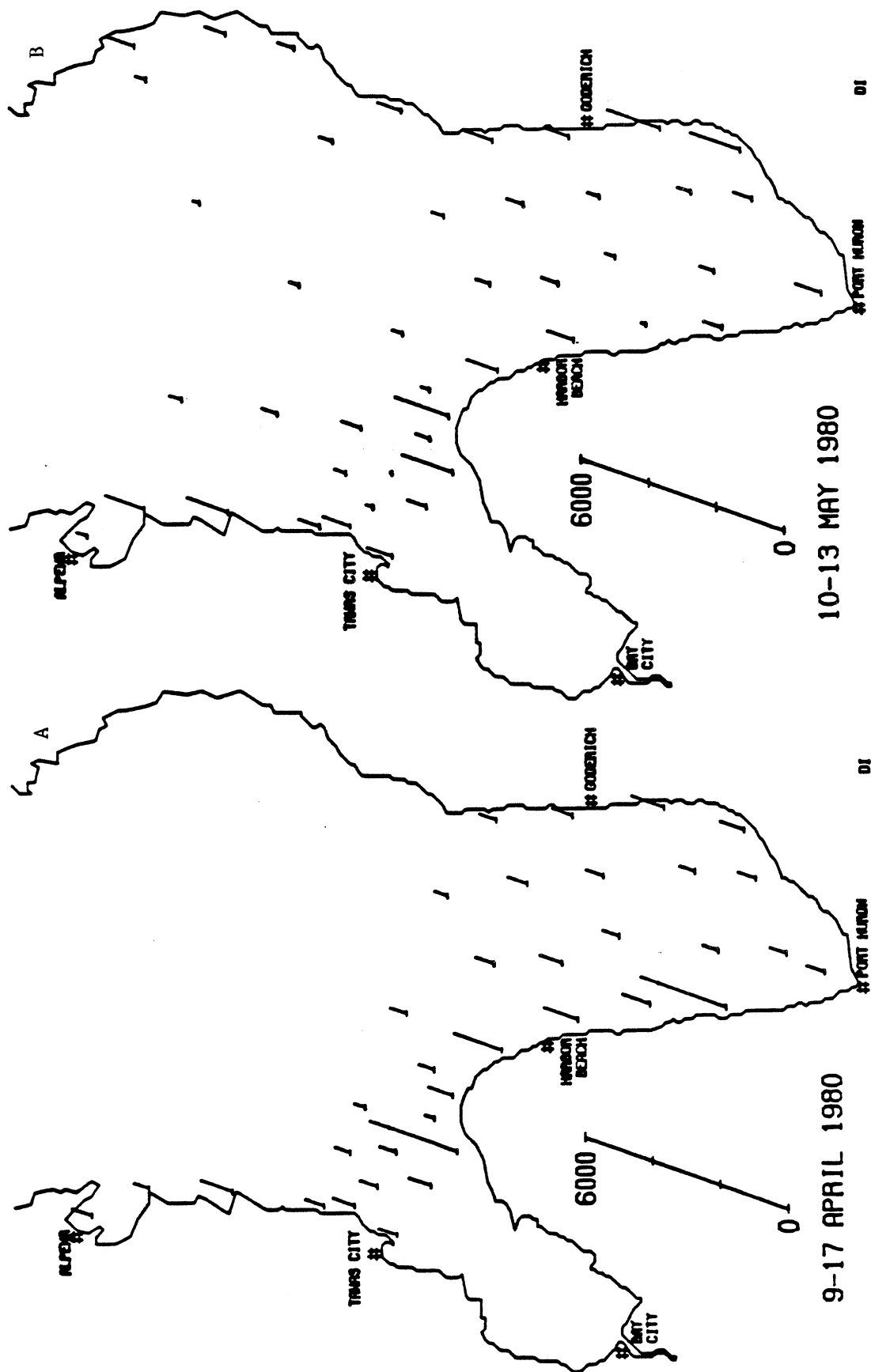


FIG. 10. Seasonal distribution and abundance trends (cells/mL) of diatoms, 1980.

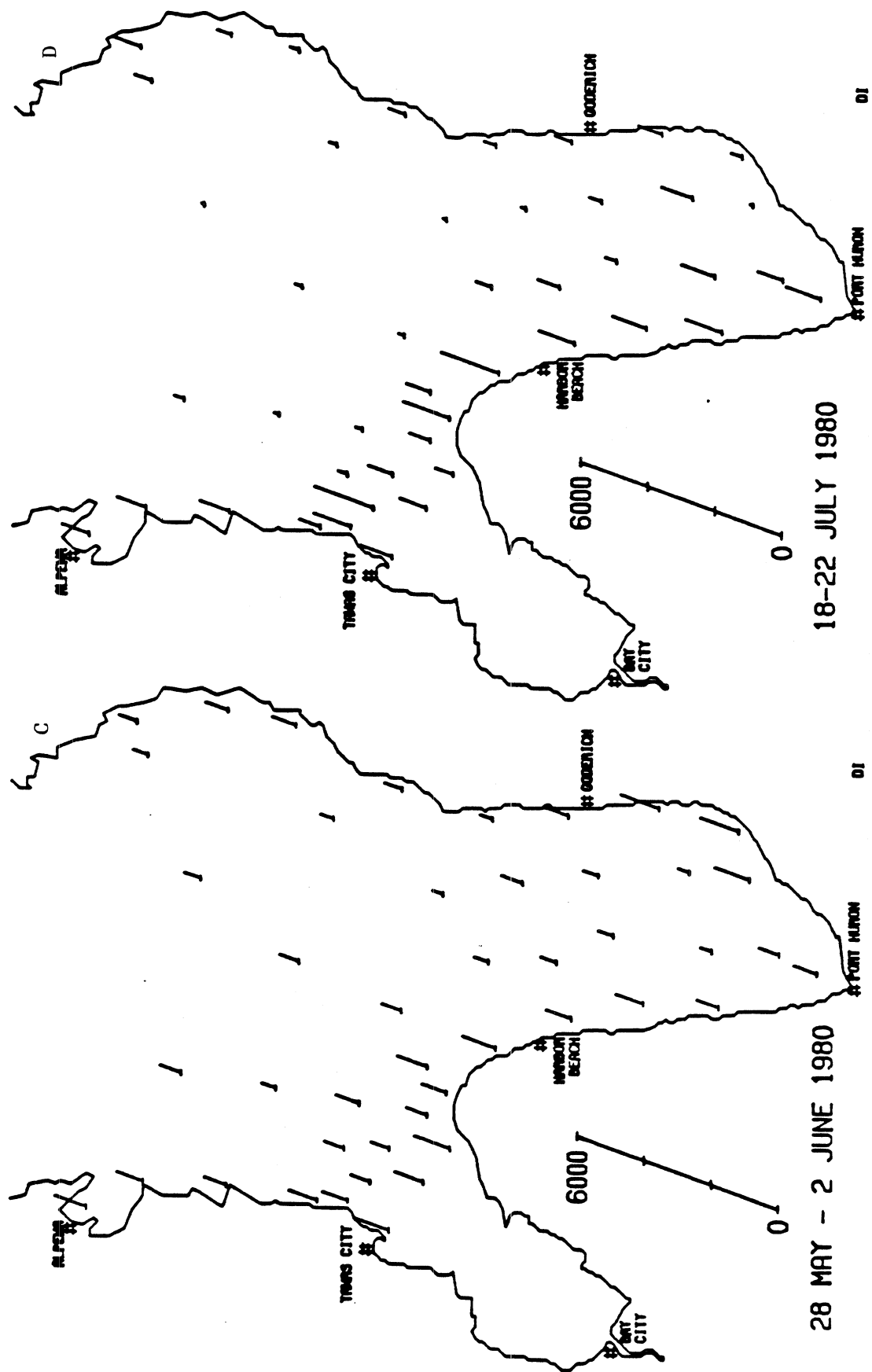


FIG. 10. (continued)

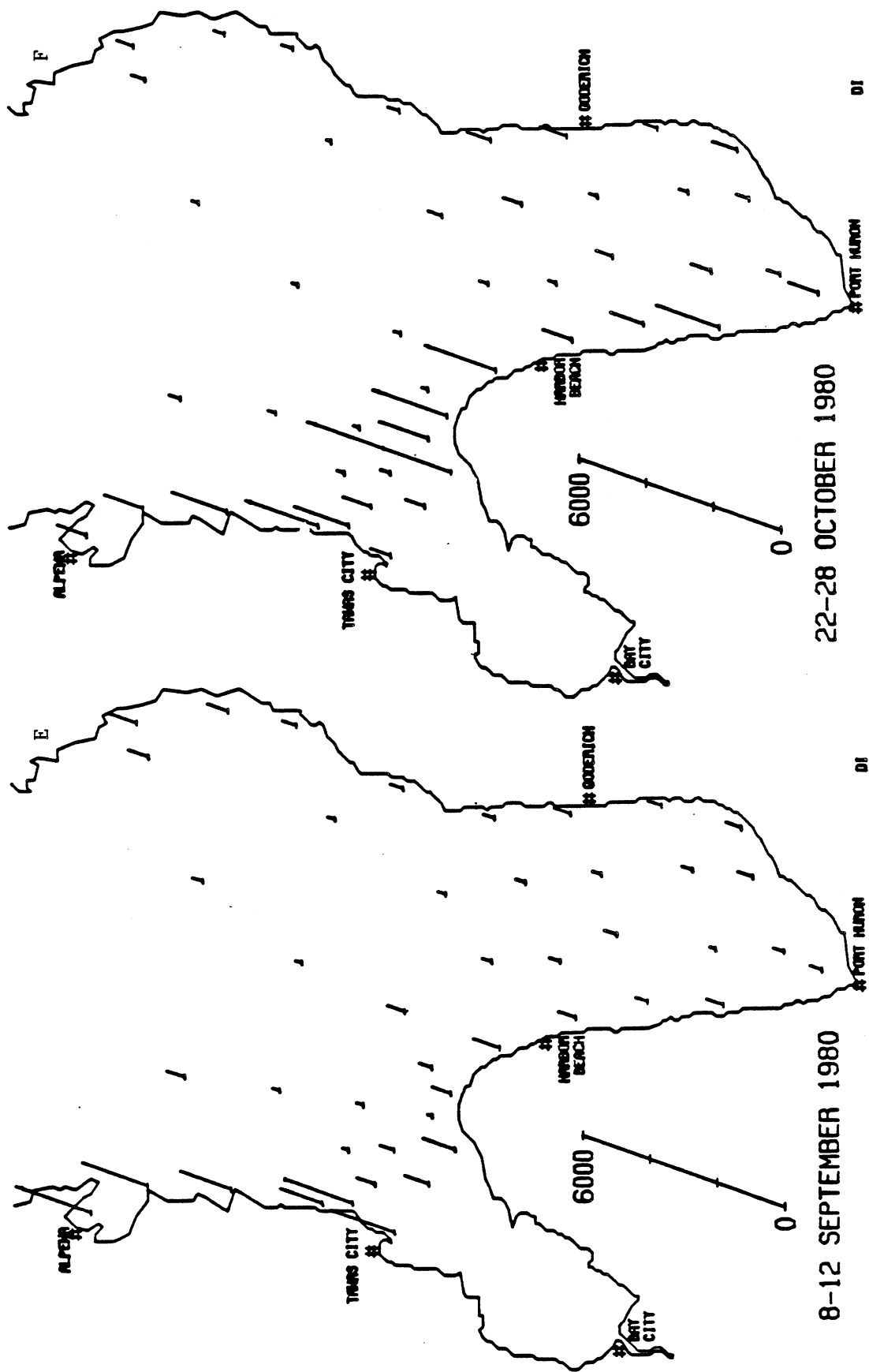


FIG. 10. (continued)

for September was the lowest for year. High cell densities were reported only for the nearshore zone between Alpena and Tawas City. In October, the largest average diatom abundance for the year was recorded. Greatest abundance was observed in Saginaw Bay. However, high concentrations were recorded for the entire U.S. coastline from Alpena through outer Saginaw Bay to Port Huron (Fig. 10F). Much lower abundances were observed in the offshore waters and the Canadian nearshore areas.

Asterionella formosa--

This species is cosmopolitan, occurring in a number of different habitats and exhibiting a wide range of pollutional tolerance. It has previously been reported from all of the Great Lakes. During April (Fig. 11A), it attained its greatest abundance in the southern basin, particularly in the U.S. sector of the basin. In May (Fig. 11B), reduced abundances were seen in the southern basin and a comparatively larger standing crop was observed in the central basin. This trend was extended and amplified in June (Fig. 11C), with highest standing crops in the central basin. Notably reduced cell numbers were observed in July (Fig. 11D), with the highest abundances occurring in the U.S. nearshore zone particularly south of Alpena. Continued abundance reduction was observed for September (Fig. 11E), with most occurrences in nearshore areas. In October (Fig. 11F), elevated abundances were observed in both basins compared to September and a large peak recorded north of Goderich in the Canadian nearshore zone.

Cyclotella comensis--

This species was recorded from the Great Lakes only in the past decade but has exhibited very large abundances in Lake Huron (Lowe 1976, Stoermer and

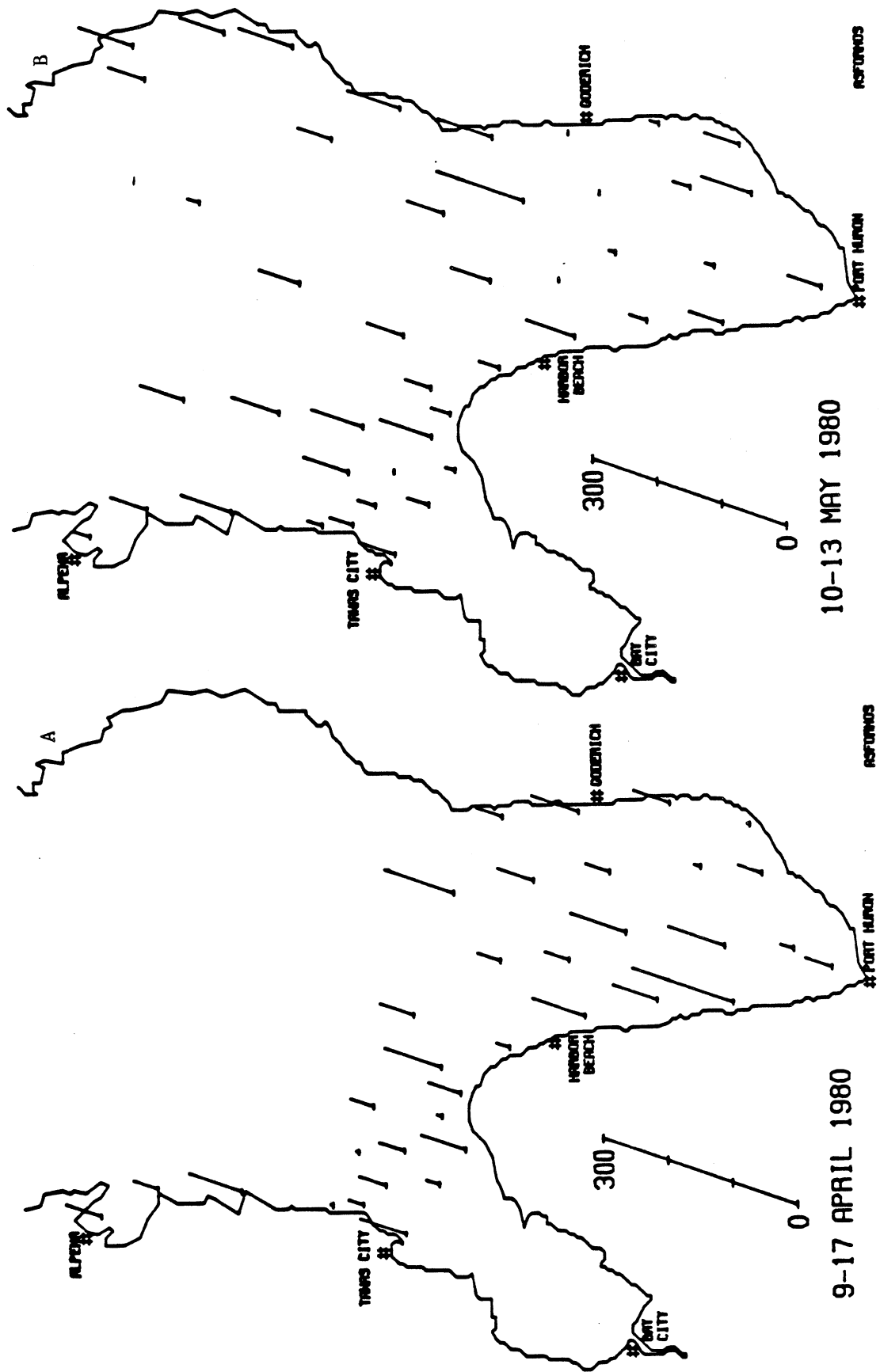


FIG. 11. Distribution of *Asterionella formosa*.

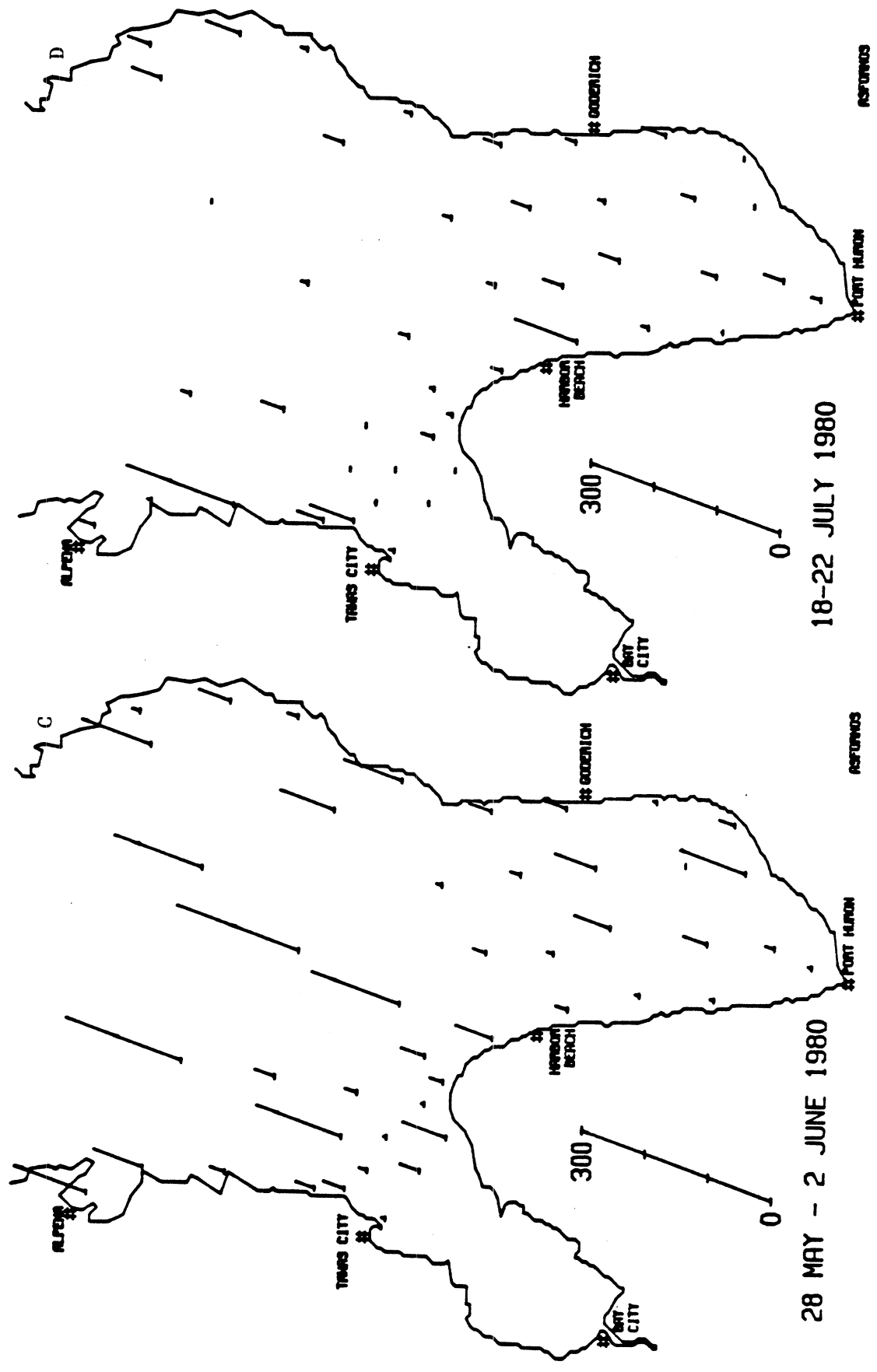


FIG. 11. (continued)

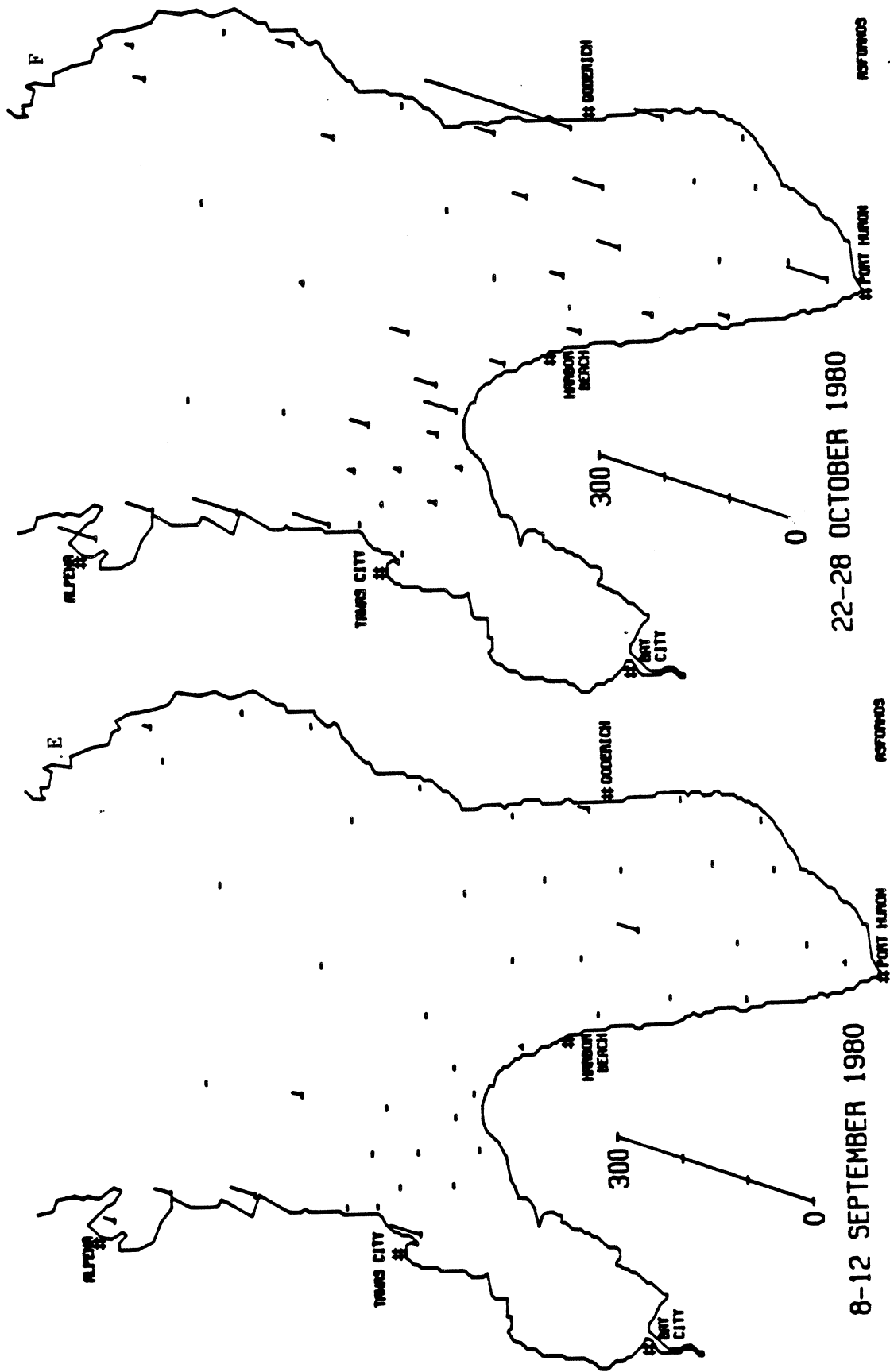


FIG. 11. (continued)

Kreis 1980, Ladewski et al. 1982). During April (Fig. 12A), abundances were uniformly low. In May (Fig. 12B), reduced abundances were observed, yet it was widely distributed with highest standing crops reported between Alpena and Tawas City. During June, highest cell numbers were observed along the entire U.S. shoreline and the Saginaw Bay interface waters (Fig. 12C). Generally, the offshore waters of both basins showed low, uniform abundances. Increased cell densities were noted in July (Fig. 12D), particularly in the Saginaw Bay interface waters and in the southern basin. Very low abundances were seen in the offshore waters of the central basin. Largest standing crops for the year were recorded during September (Fig. 12E). Large concentrations of this species were seen between Alpena and Tawas City with reduced abundances in the southern basin. Highest abundances in the open central basin were also noted during this month. Standing crops were generally reduced during October (Fig. 12F), with highest cell numbers observed in the U.S. sector of the lake.

#### Cyclotella comta--

Cyclotella comta is commonly noted in the plankton of the Great Lakes but is reduced in areas that have been adversely impacted. During April through June (Figs. 13A-13C), it showed very low abundances and sporadic occurrences at stations in outer Saginaw Bay and in the interface zone. In July (Fig. 13D), it was observed in the northern Canadian shoreline and slightly elevated abundances were seen in outer Saginaw Bay and particularly along the coastline north of Tawas City. It reached its maximum abundance and widest distribution for the year in September (Fig. 13E), with highest concentrations being observed north of Tawas City along the shore and in the western sector

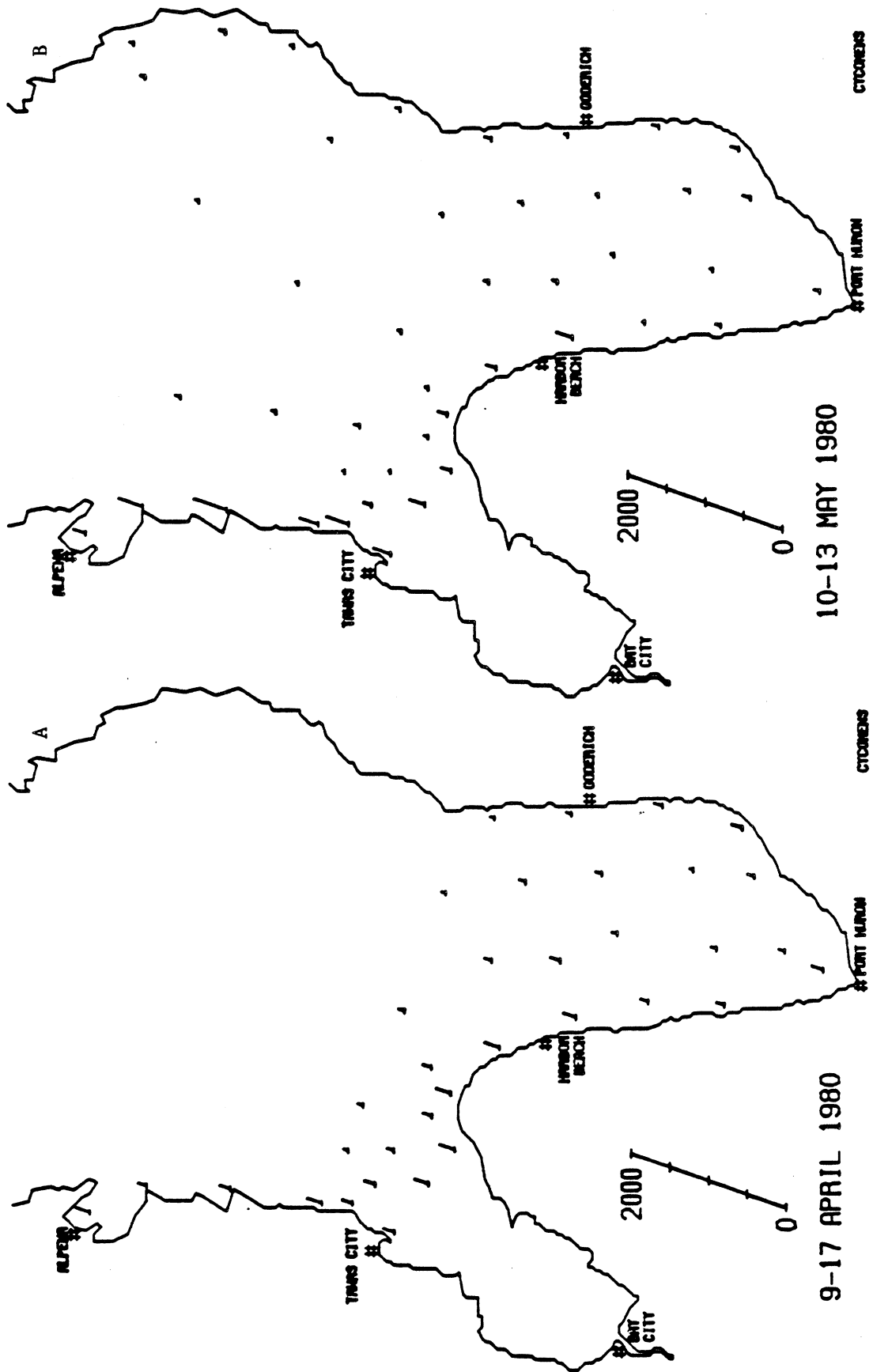


FIG. 12. Distribution of *Cyclotella comensis*.

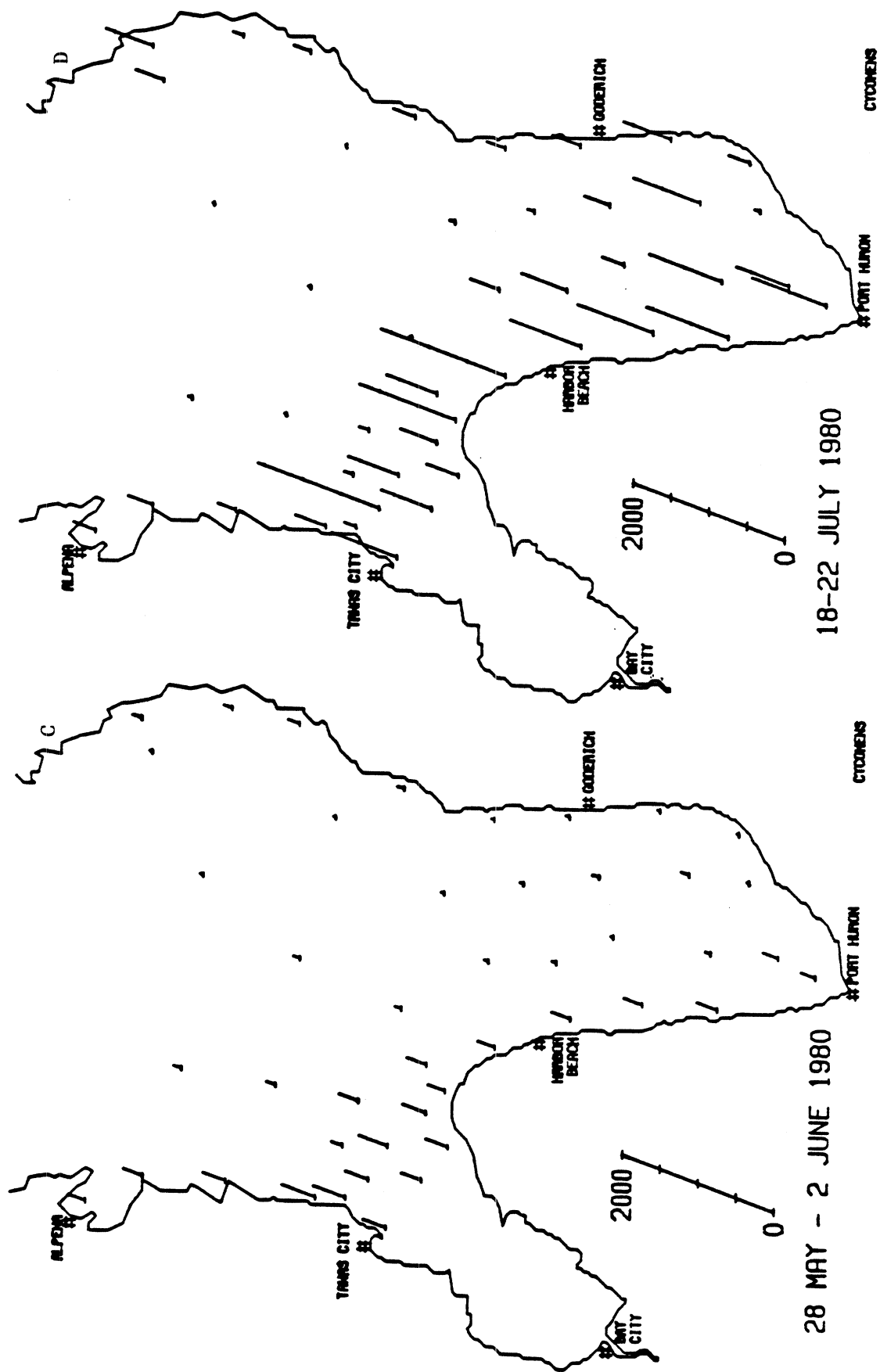


FIG. 12. (continued)

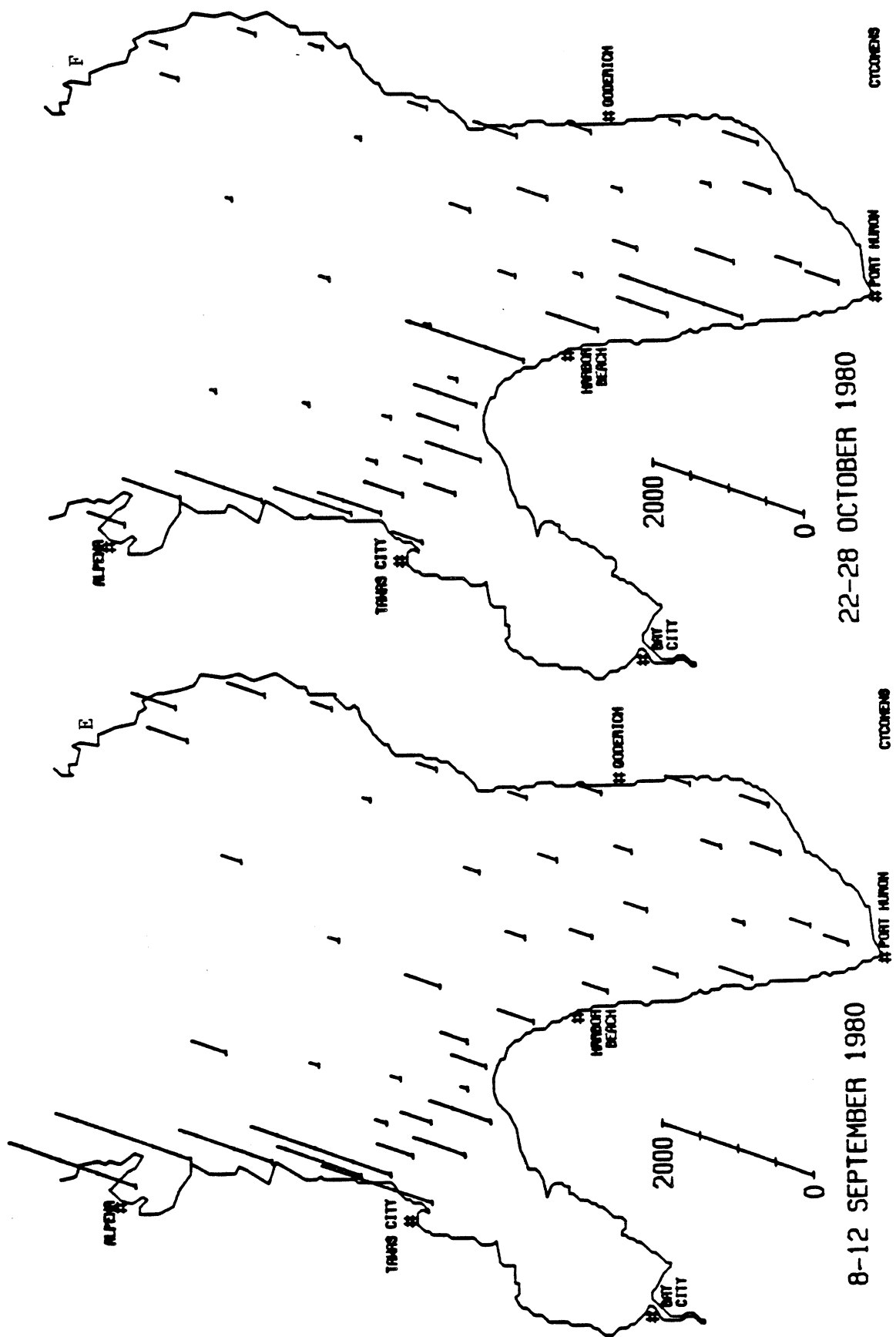


FIG. 12. (continued)

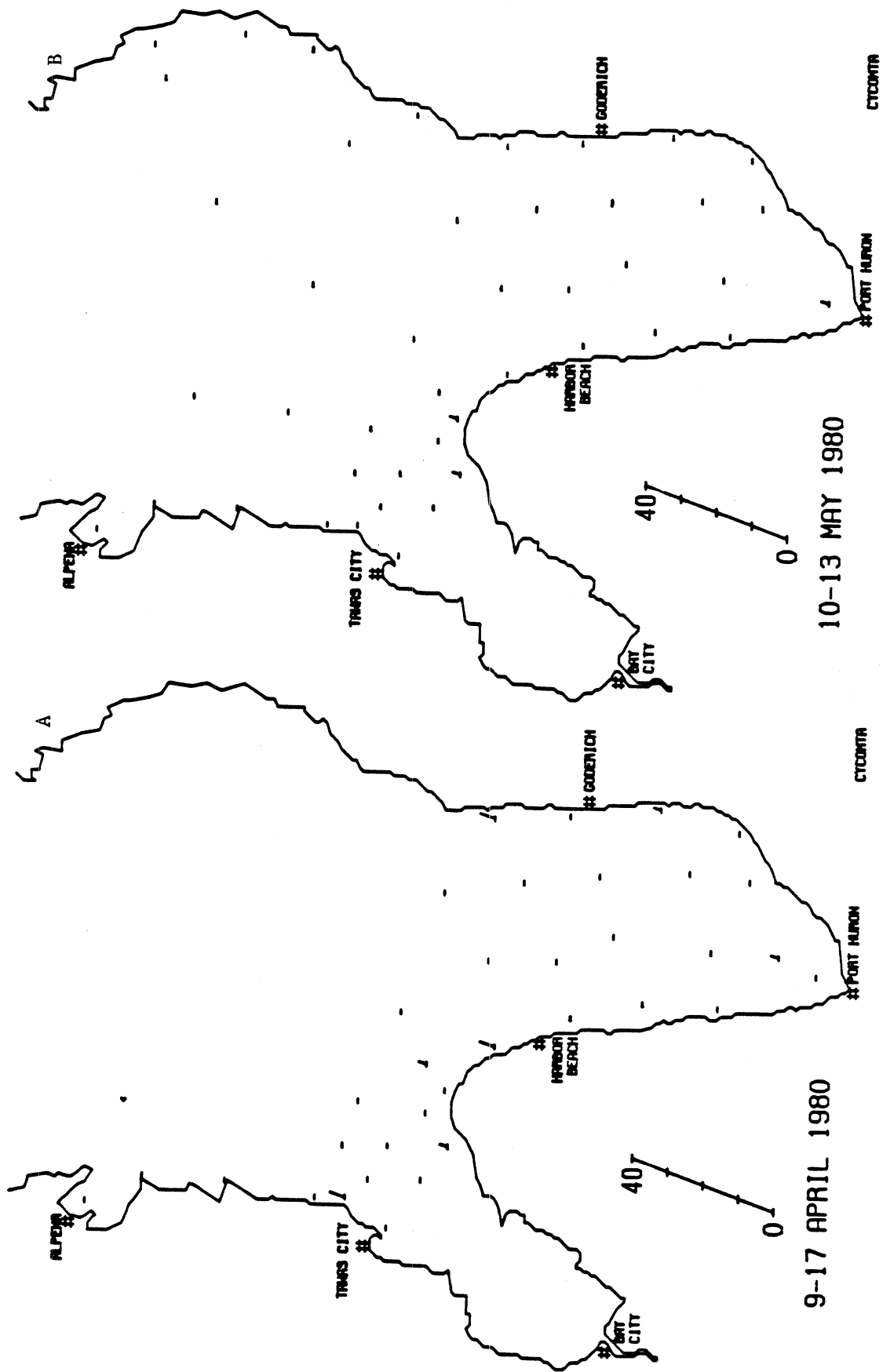


FIG. 13. Distribution of *Cyclotella comta*.

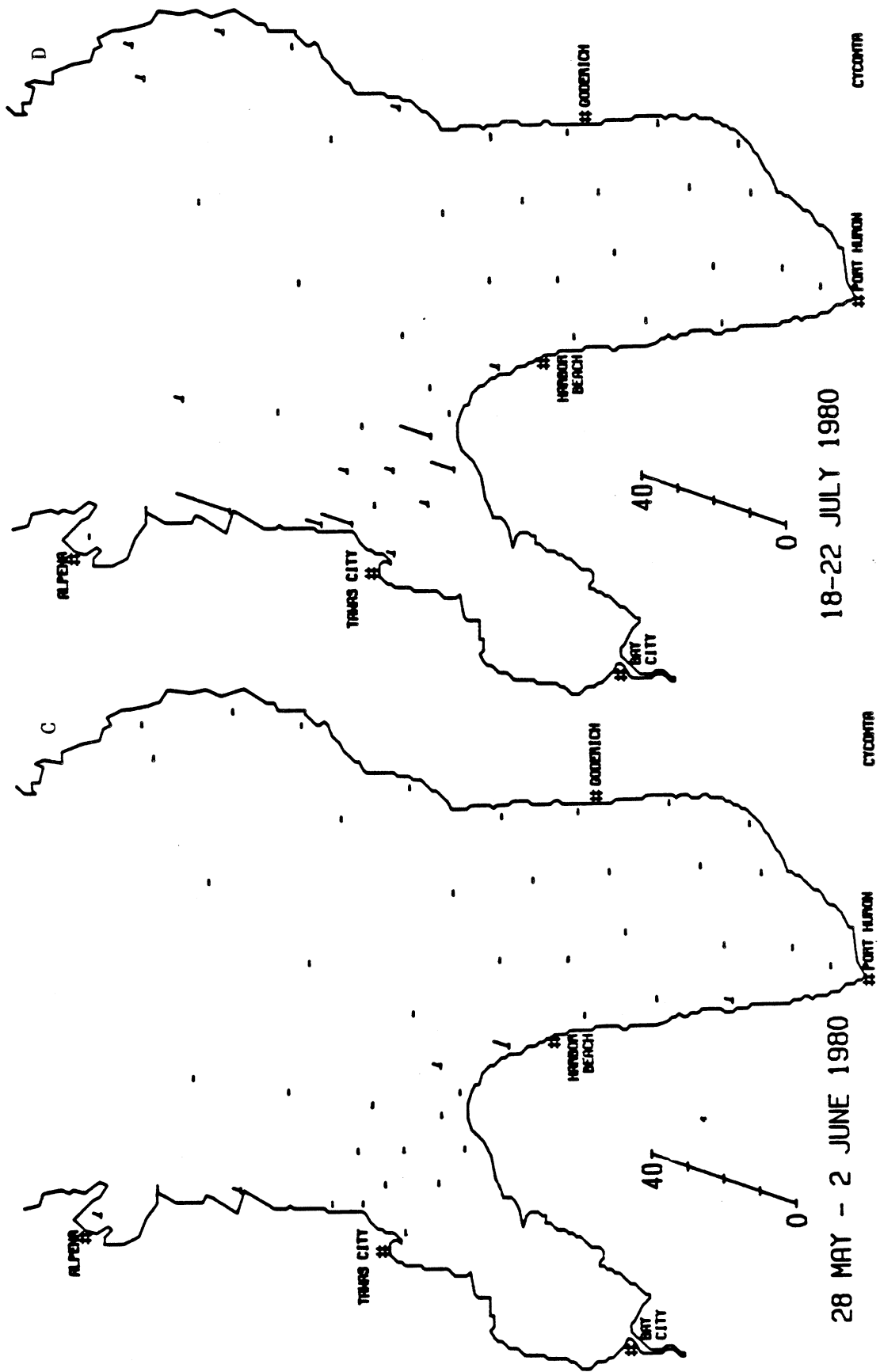


FIG. 13. (continued)

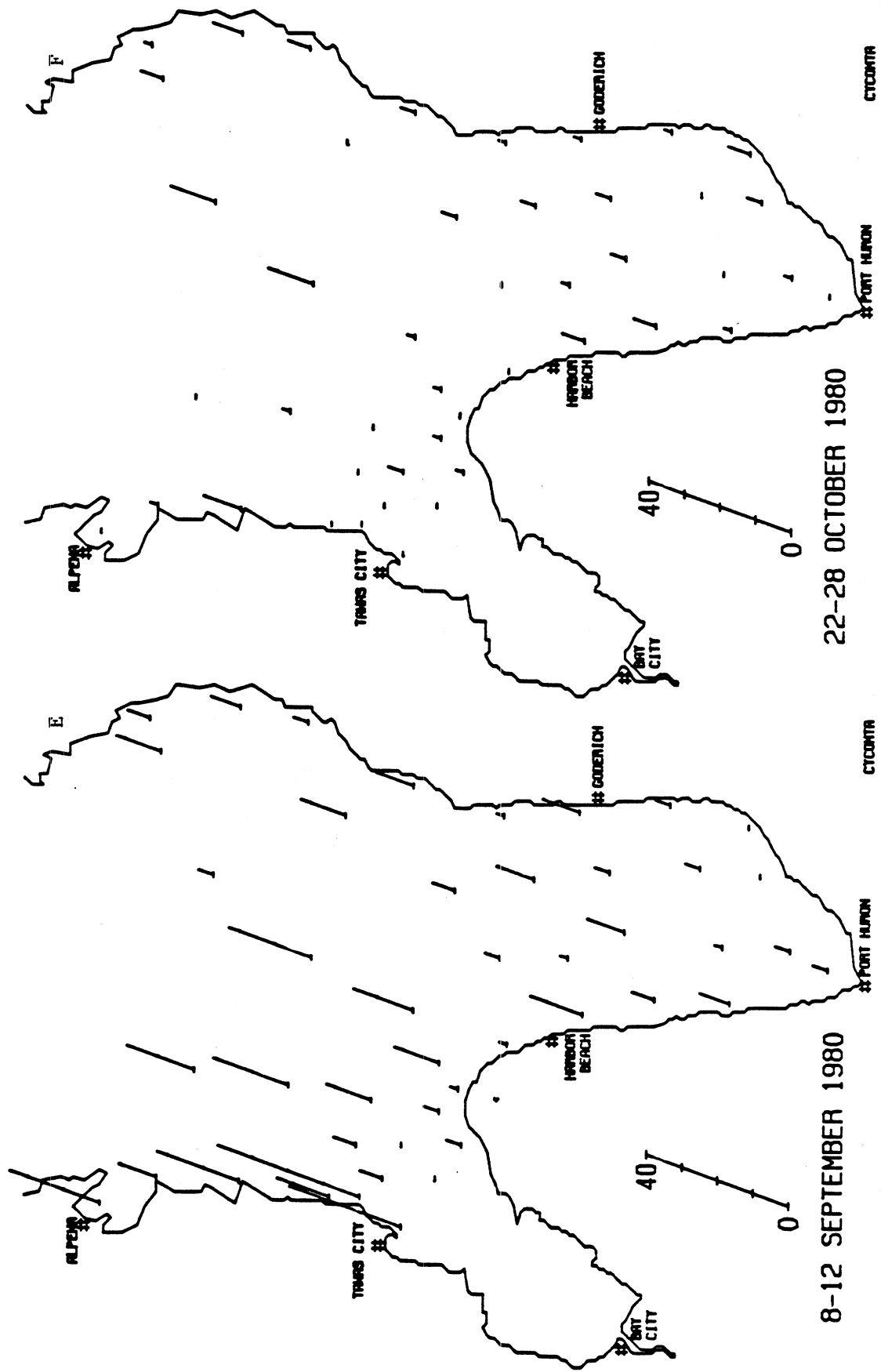


FIG. 13. (continued)

of the central basin. Reduced abundances and distribution were recorded for October (Fig. 13F), with highest densities seen in the mid-central basin.

#### Cyclotella michiganiana--

This diatom was originally found and described from Lake Michigan by Skvortzow (1937). It has also been observed in the inland lakes of the State of Michigan (Stoermer 1977, Andresen and Stoermer 1978). In April (Fig. 14A), this species reached its greatest abundance for the year. It occurred in nearshore areas of the U.S. sector with highest abundance in outer Saginaw Bay and southward. It was substantially reduced in abundance during May (Fig. 14B) but was widely distributed over the study area. Low abundances were seen in June (Fig. 14C), with most occurrences restricted to the offshore waters of the southern basin. During July (Fig. 14D), low abundances were again observed with most occurrences in the central basin. During September (Fig. 14E), slightly higher standing crops were observed with highest peaks in the nearshore zone between Alpena and Tawas City. In October (Fig. 14F), occurrences were predominantly in the nearshore zone of the U.S. sector.

#### Cyclotella ocellata--

Populations of this centric diatom are usually associated with periods of cooler water temperatures and are also observed during upwelling events and near the thermocline in the Great Lakes. It is an important component of assemblages in northern Lake Huron (Stoermer et al. 1976). Stoermer and Yang (1968) also found this species to be the dominant in their core from northern Lake Huron. In April (Fig. 15A), C. ocellata was observed in high abundances showing a wide, uniform distribution over the study area with peaks in the Canadian nearshore, the northern U.S. coast, and in the open southern basin.

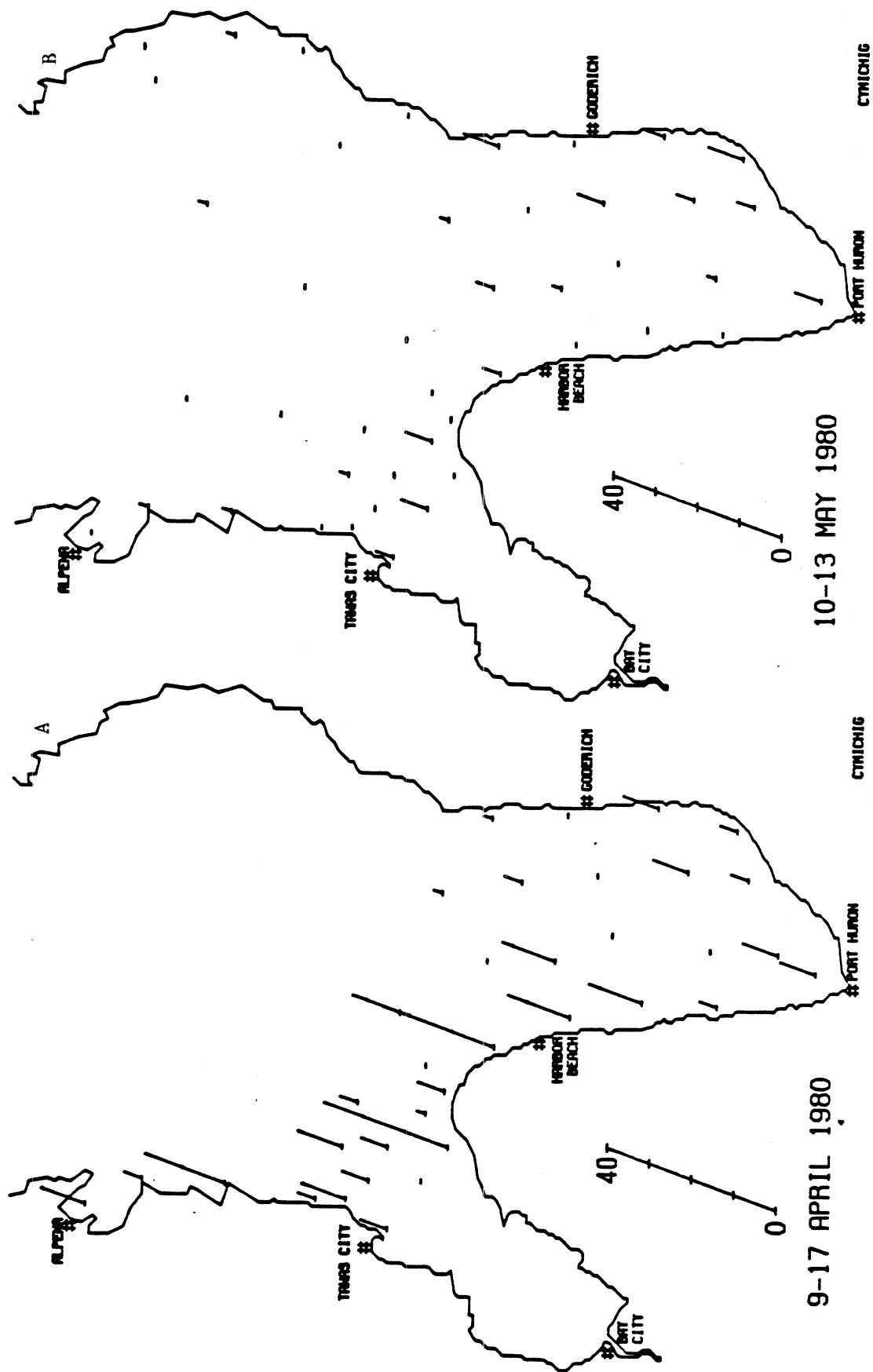


FIG. 14. Distribution of *Cyclotella michiganiana*.

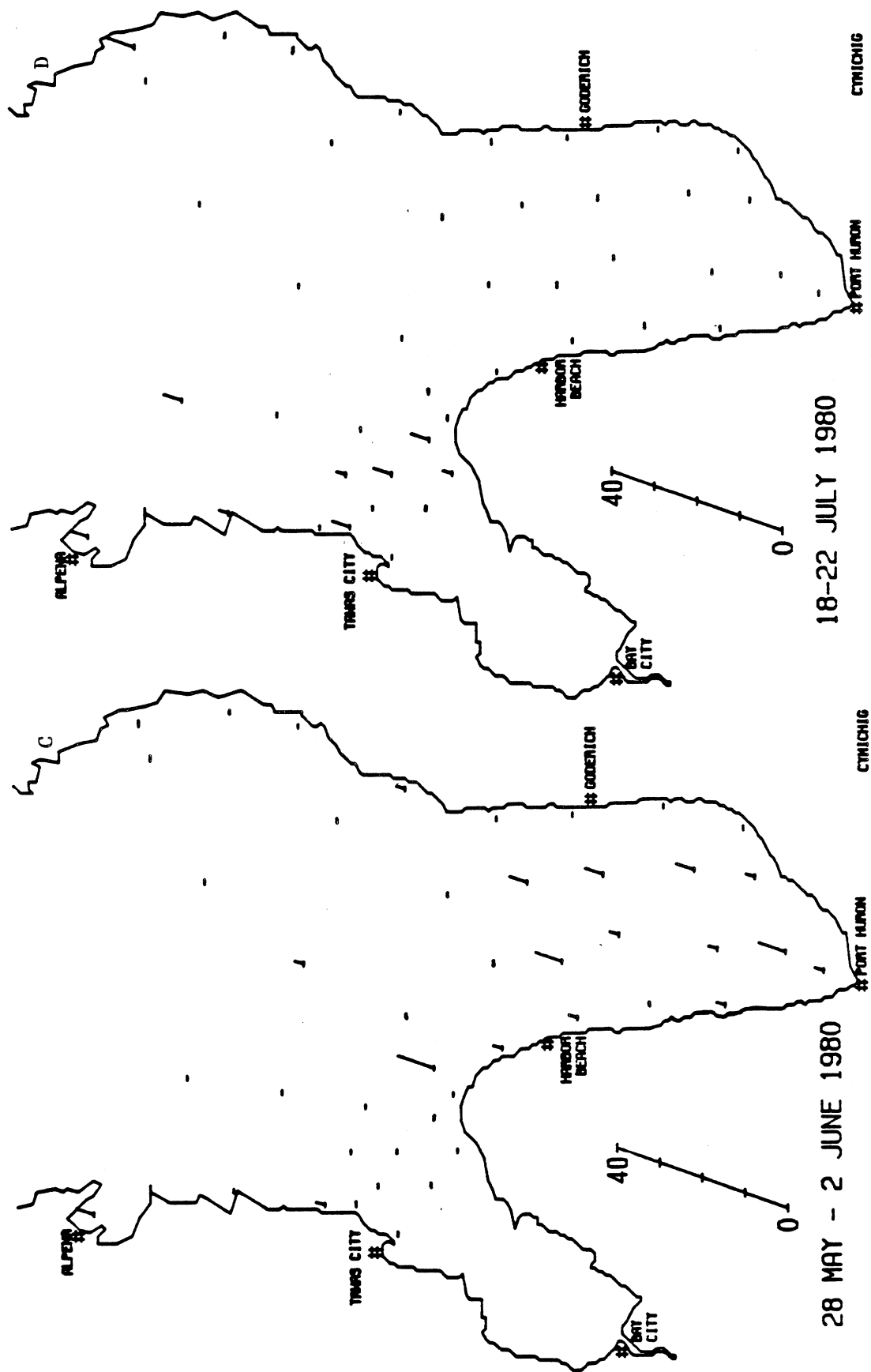


FIG. 14. (continued)

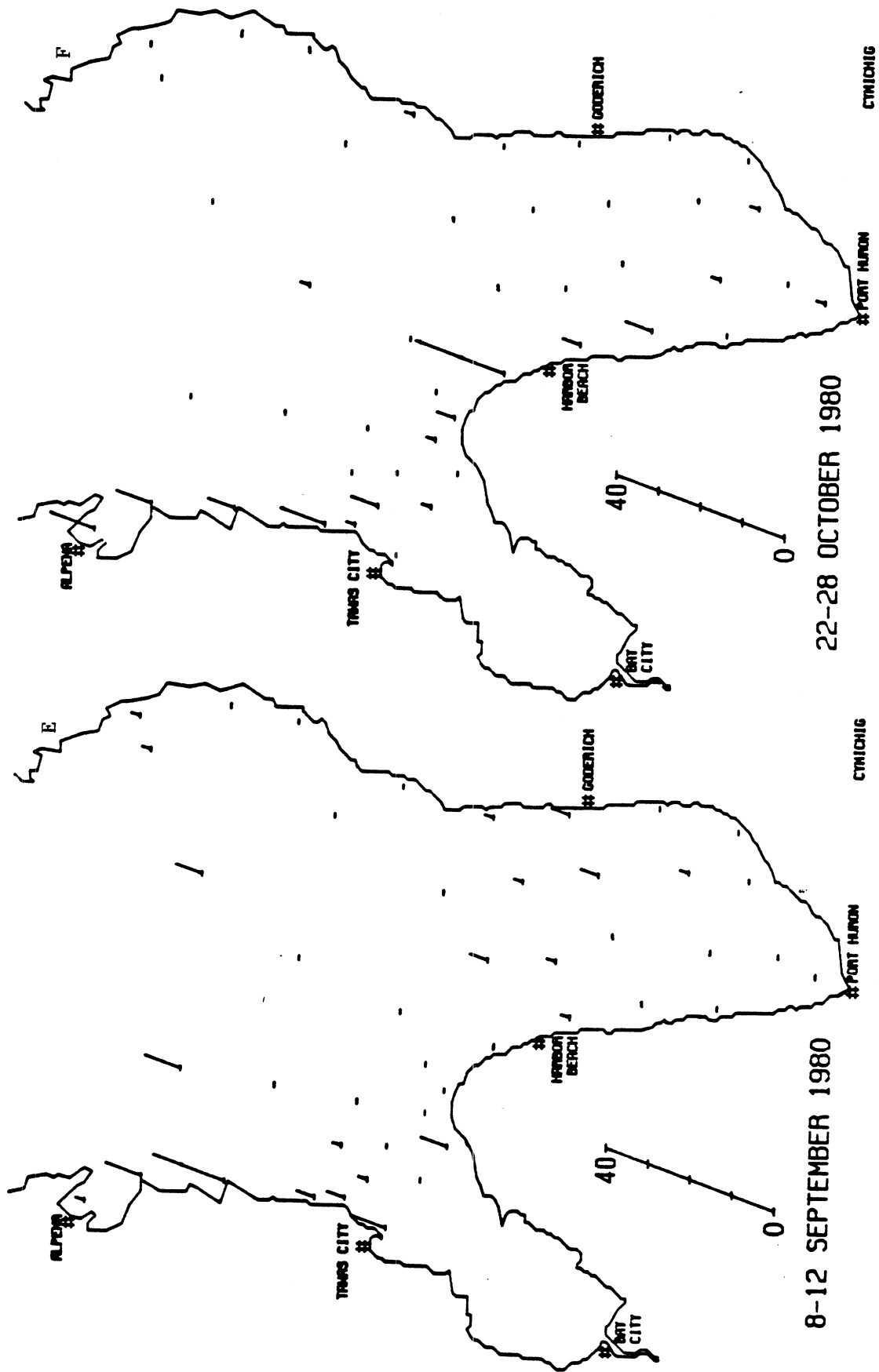


FIG. 14. (continued)

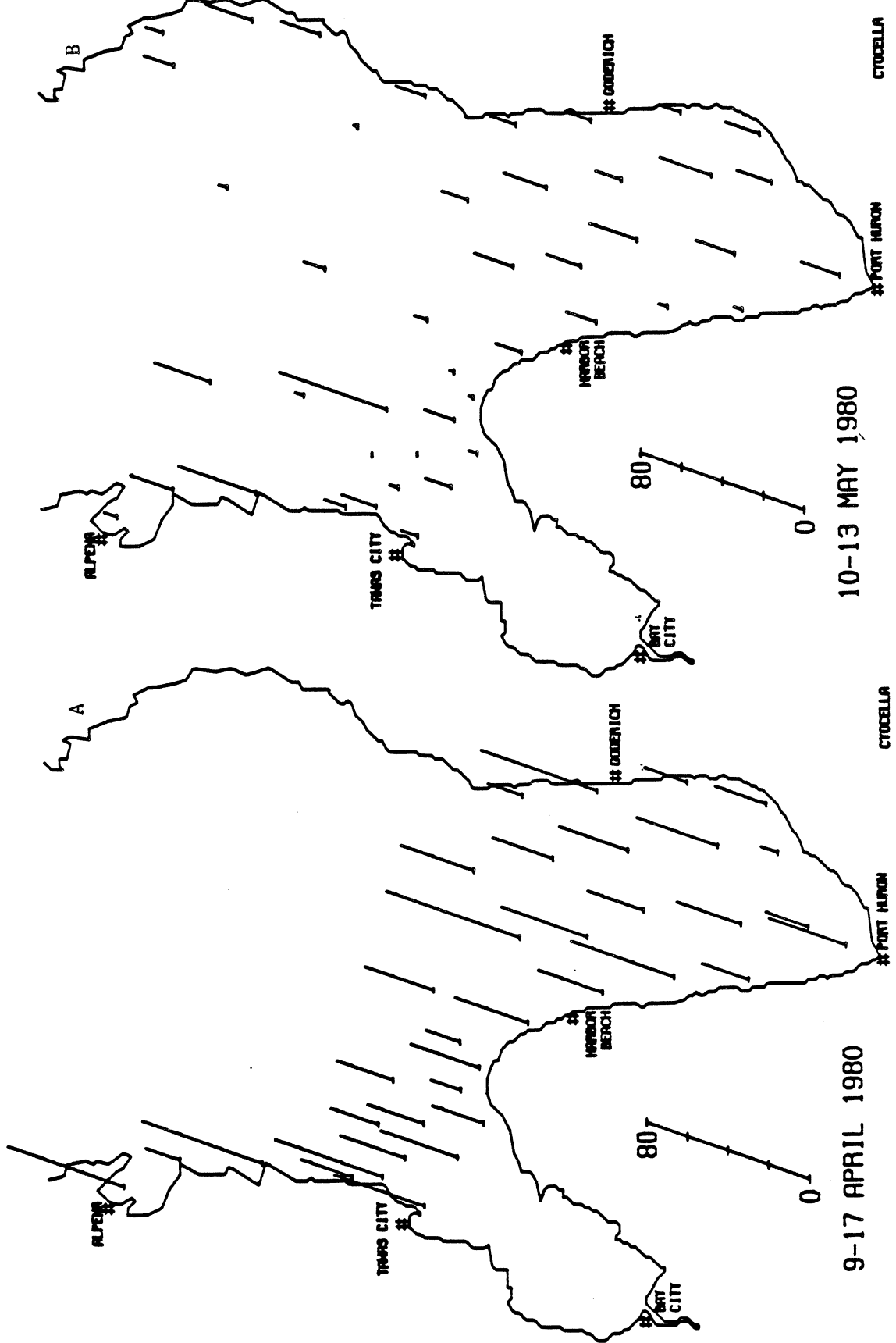


FIG. 15. Distribution of *Cyclotella ocellata*.

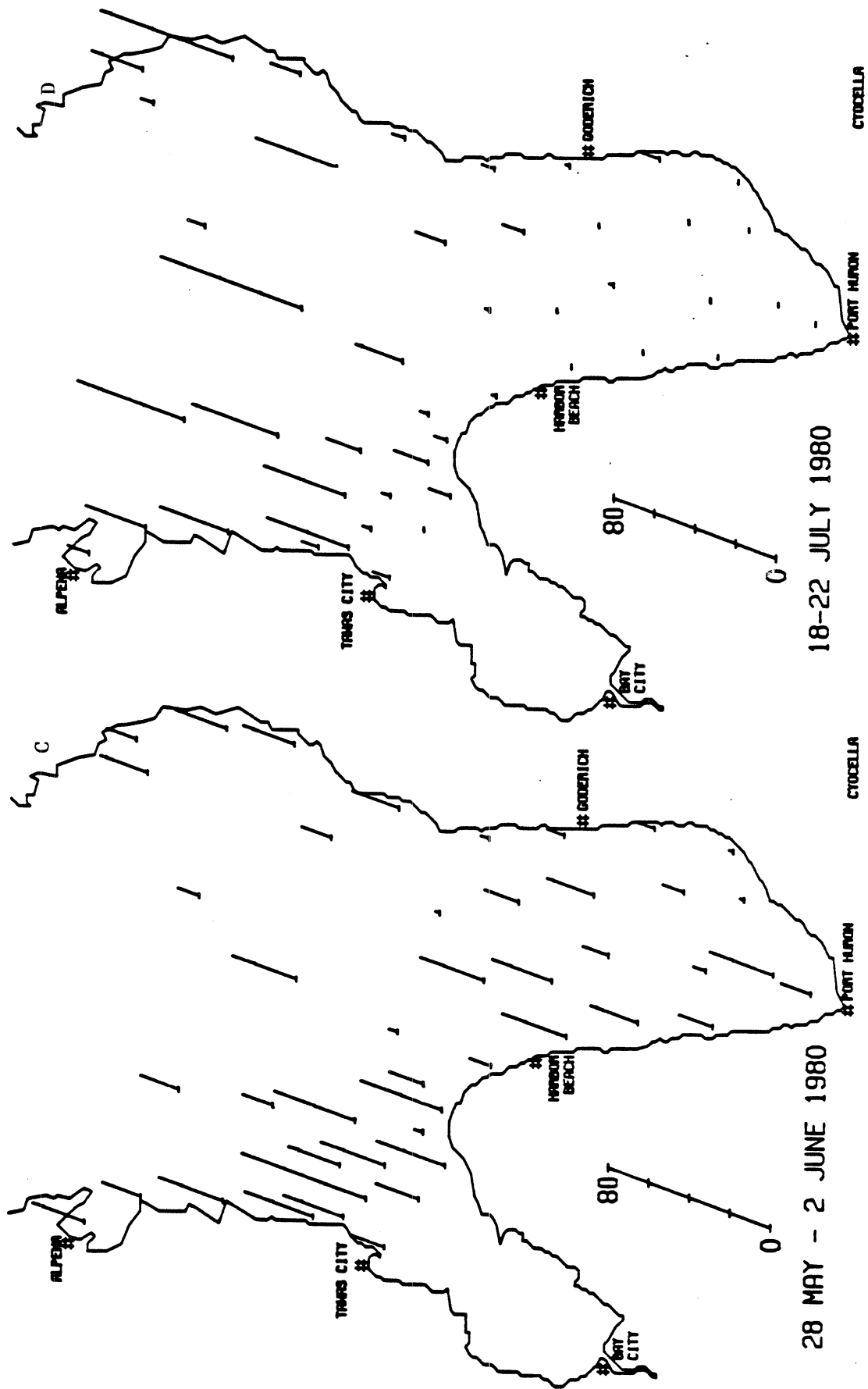


FIG. 15. (continued)

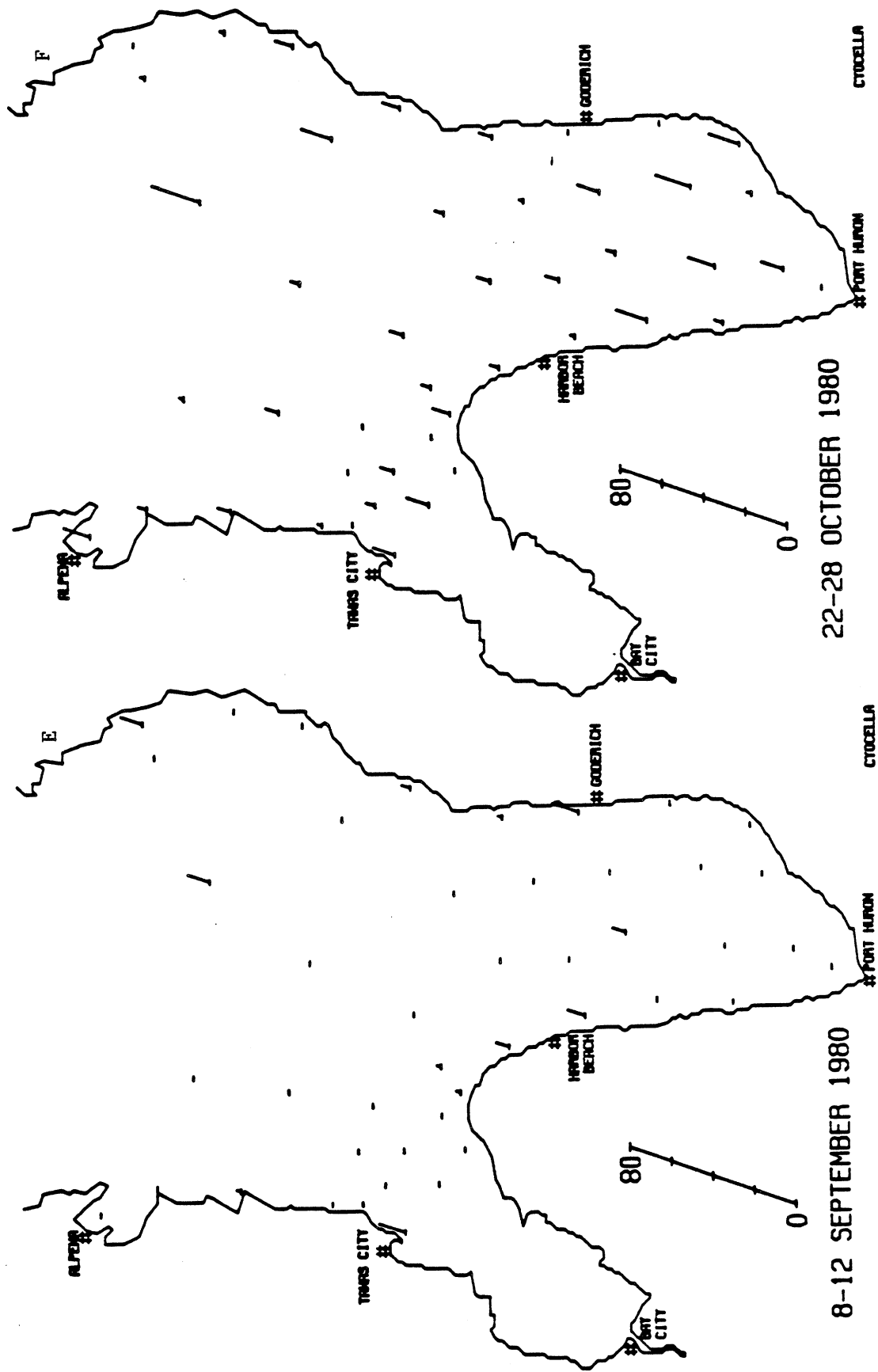


FIG. 15. (continued)

Reduced densities were observed in May (Fig. 15B), with highest abundances in the western portion of the central basin. It showed higher abundances in the offshore waters of the southern basin compared to the nearshore zone. In June (Fig. 15C), increased abundances were seen lakewide, with higher standing crops observed in the U.S. sector of the lake. During July (Fig. 15D), this species was nearly eliminated from the southern basin with greatest abundances in the open central basin. Populations were substantially reduced over the entire area in September (Fig. 15E), with only sporadic occurrences. Slightly elevated abundances and a wide distribution were exhibited in October (Fig. 15F), with highest concentrations in open waters.

Cyclotella pseudostelligera--

This taxon generally attains its greatest abundance in nearshore areas and is associated with rivermouth outflows in the Great Lakes. However, this study indicates that it may extend its distribution into the open waters. This taxon was not observed until June (Fig. 16A) when it was recorded from two stations in the Canadian nearshore zone. In July (Fig. 16B), highest abundances were seen in the nearshore zone between Alpena and Tawas City and the Saginaw Bay interface area and adjacent waters to the north. C. pseudostelligera increased to its greatest abundance and widest occurrence in September (Fig. 16C). It was distributed over the entire southern basin, with largest peaks on the Canadian nearshore sector. This time period was the single clearest example of C. pseudostelligera extending its distribution to the offshore waters of Lake Huron. It was also observed in nearshore zones of the central basin. In October (Fig. 16D), it was greatly reduced in abundance with only a few scattered occurrences in littoral areas.

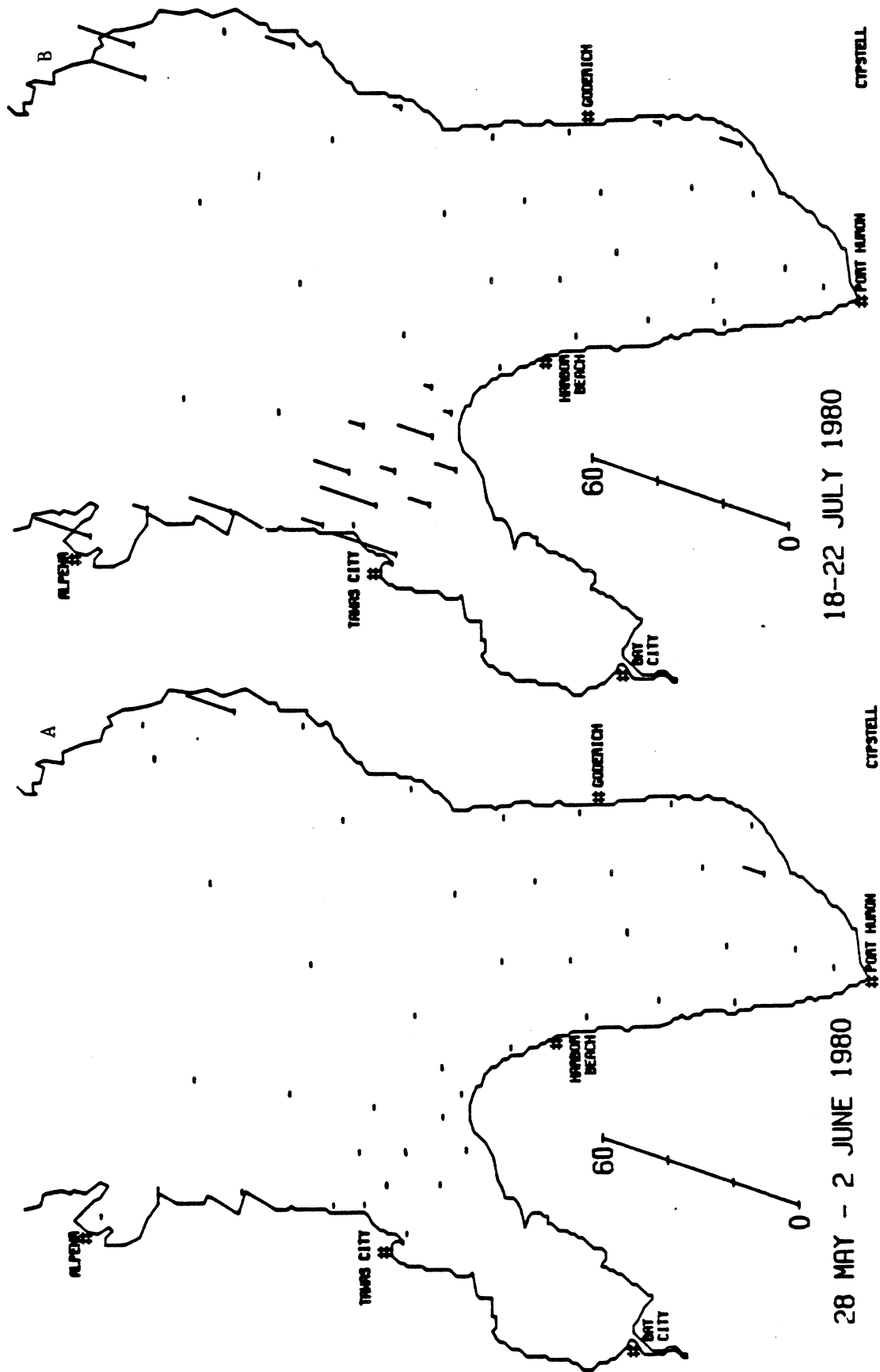


FIG. 16. Distribution of *Cyclotella pseudostelligera*.

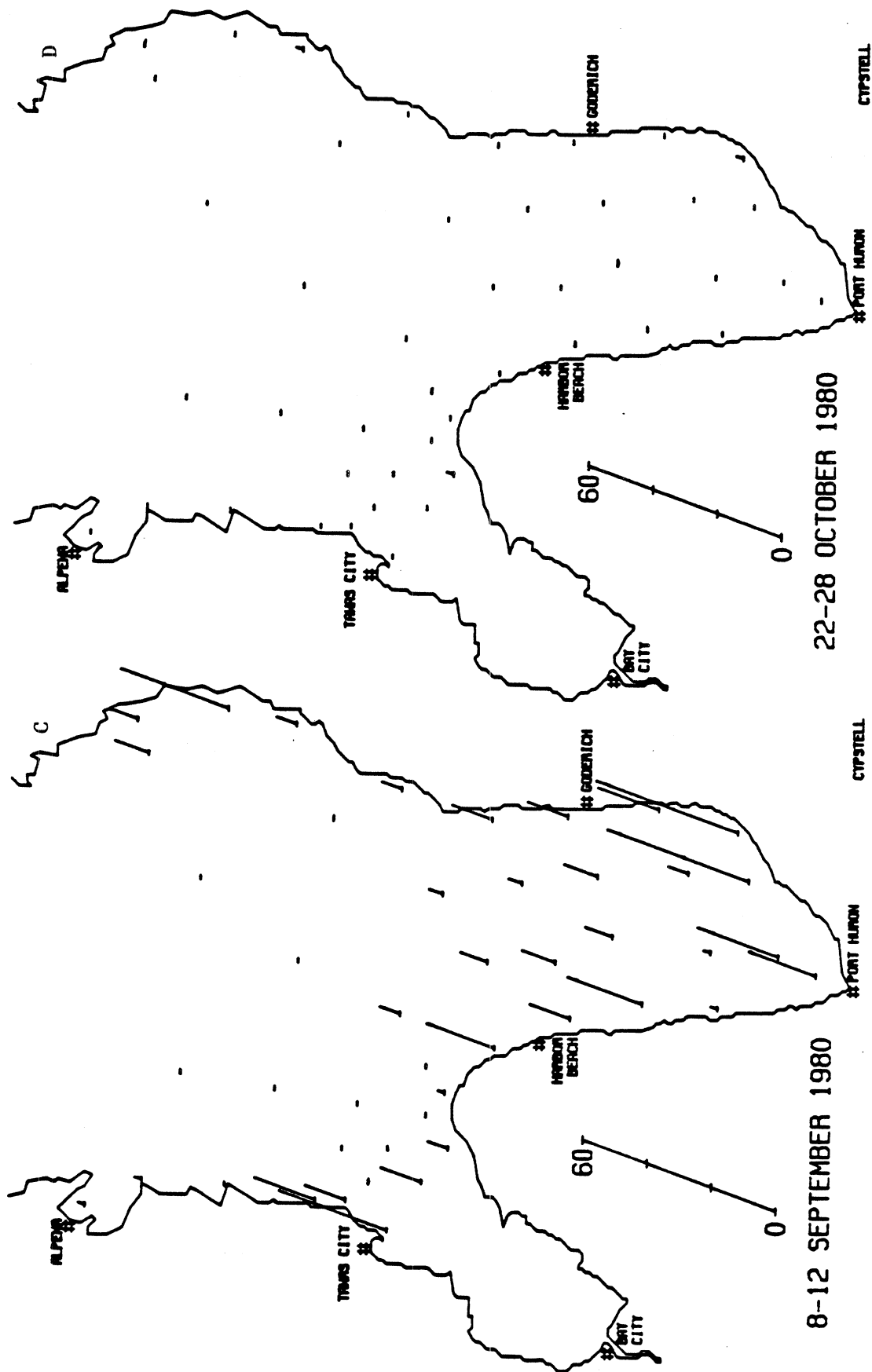


FIG. 16. (continued)

Cyclotella stelligera--

This species is commonly reported from the Great Lakes and, although it is found in oligotrophic assemblages, it may respond to slight nutrient enrichment (Schelske et al. 1972). In April (Fig. 17A), C. stelligera was uniformly distributed, with slightly higher abundances in the northern U.S. shoreline and in the open southern basin. Reduced cell numbers were observed in May (Fig. 17B) but it was widely distributed. No distinct distributional pattern was exhibited but it appeared to be most abundant in offshore areas of both basins. In June (Fig. 17C), increased abundances were noted, particularly on the shoreline between Alpena and Tawas City. It showed a very wide distribution and was slightly more abundant in the southern basin. Largest abundances for the season were noted in July (Fig. 17D), where it was particularly abundant in the north U.S. nearshore zone and in the Saginaw Bay interface. Generally, highest cell numbers were observed in nearshore areas. Reduced abundances were noted in September (Fig. 17E) but, conversely to the preceding month, greatest densities occurred in the eastern sector of the central basin. Comparatively lower abundances were observed for October (Fig. 17F). No apparent distributional trend was exhibited.

Diatoma tenue var. elongatum--

This species is associated with enriched conditions and as noted during this study finds its greatest abundance in the spring. Largest populations were seen in April (Fig. 18A), particularly in outer Saginaw Bay and the nearshore zone south of the bay. Populations were also observed in the Canadian nearshore zone of the southern basin. Reduced abundances, but a wider distribution, was observed in May (Fig. 18B), with highest cell numbers

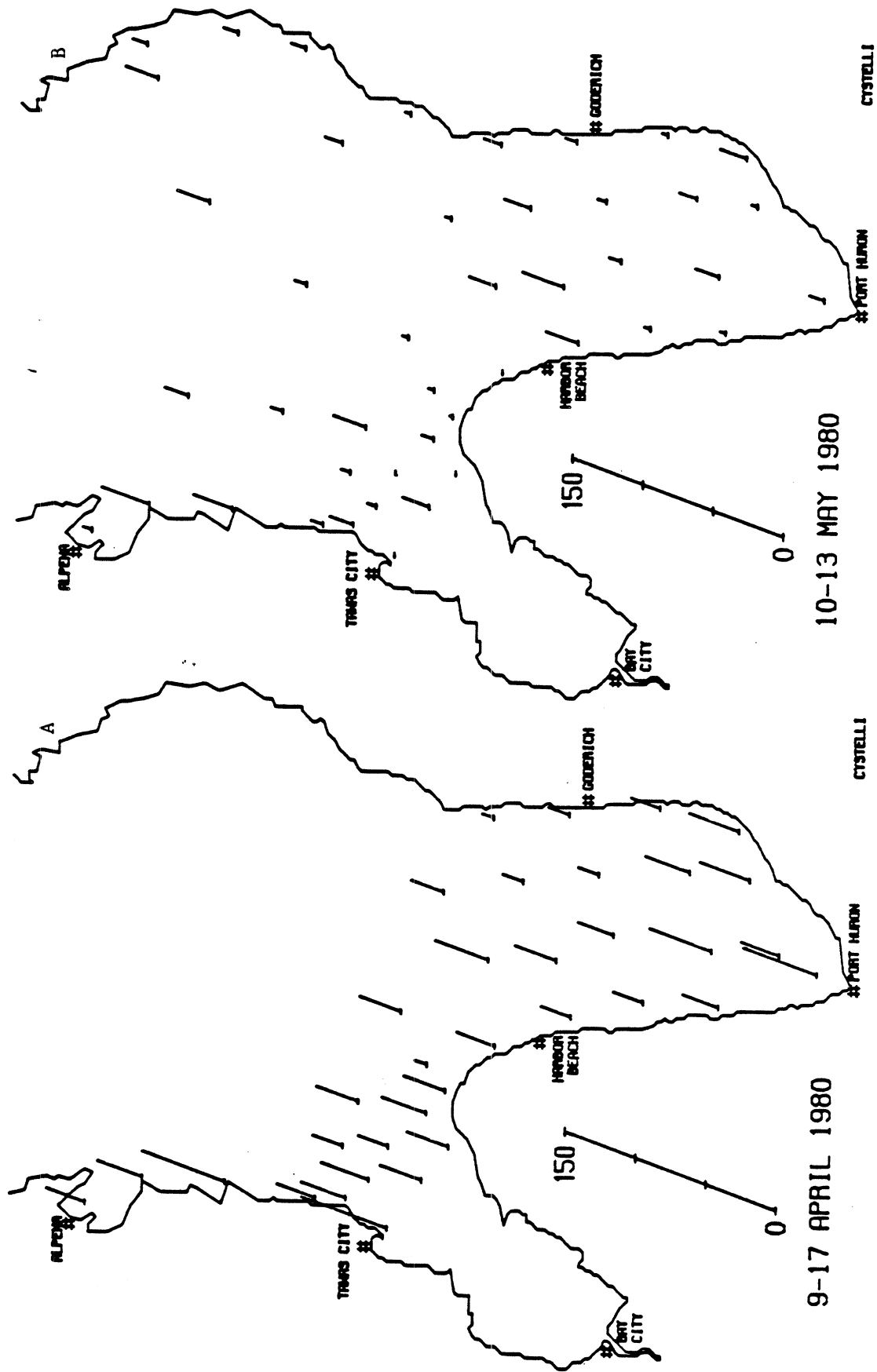


FIG. 17. Distribution of *Cyclotella stelligera*.

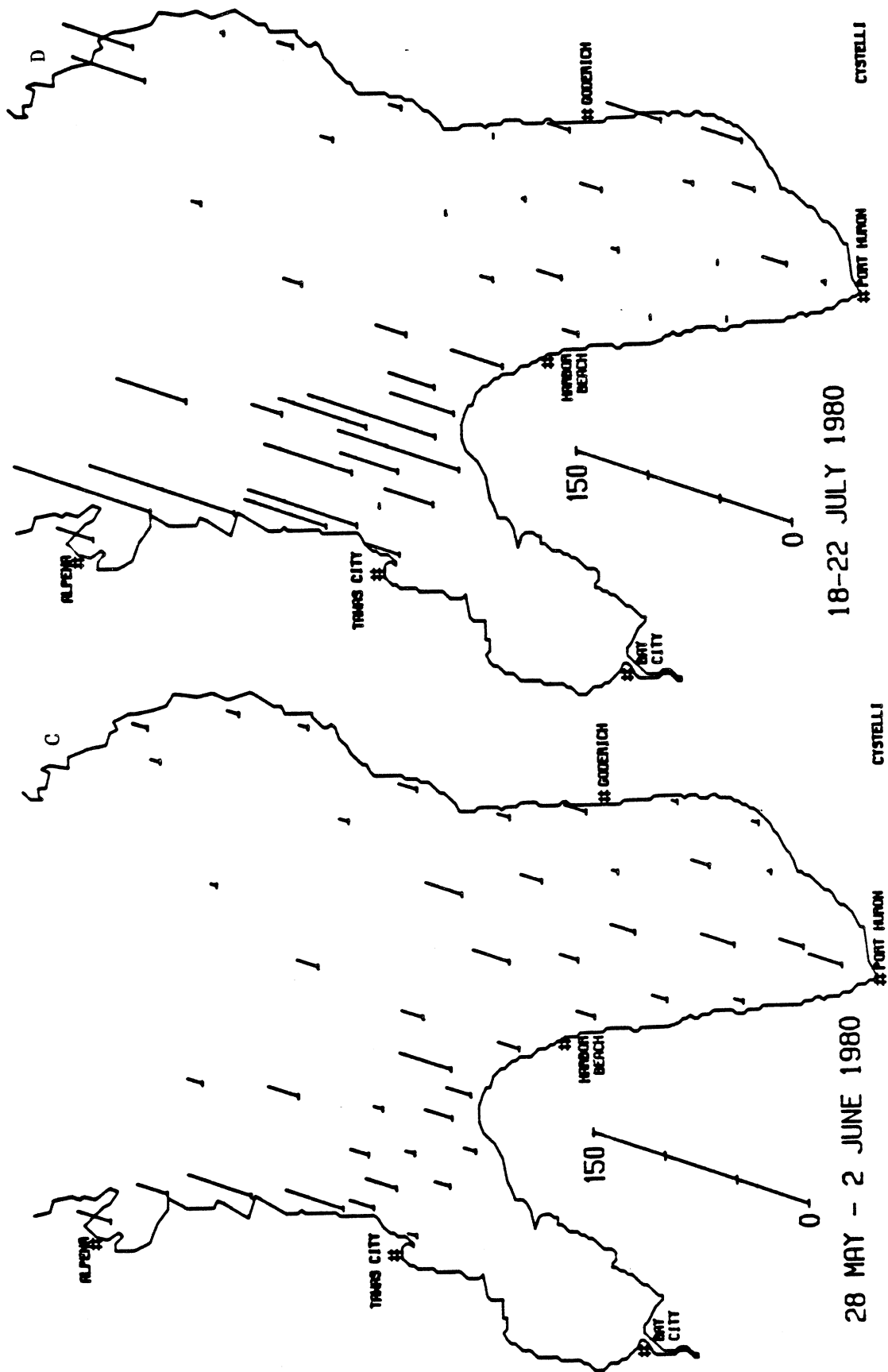


FIG. 17. (continued)

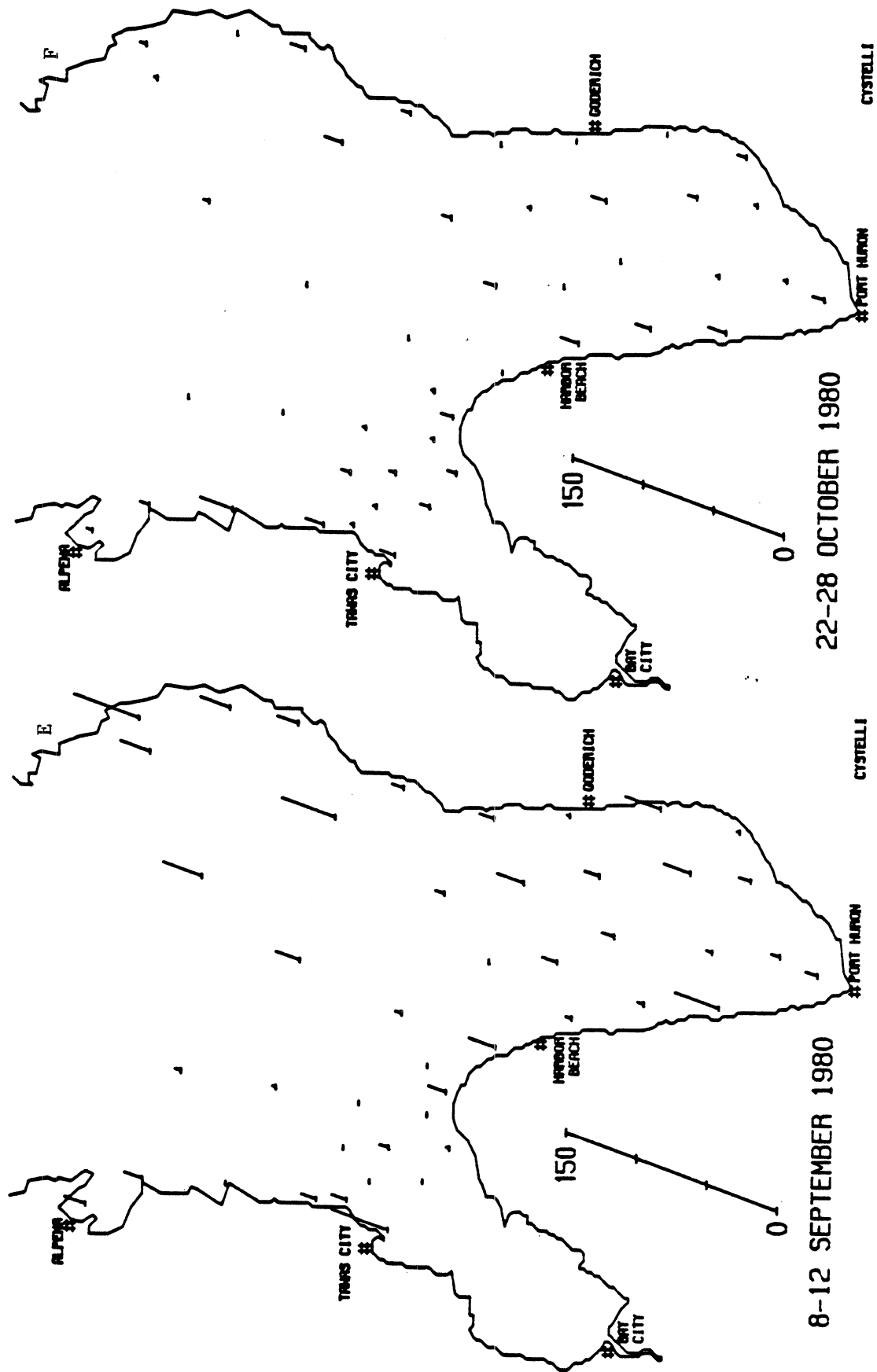


FIG. 17. (continued)

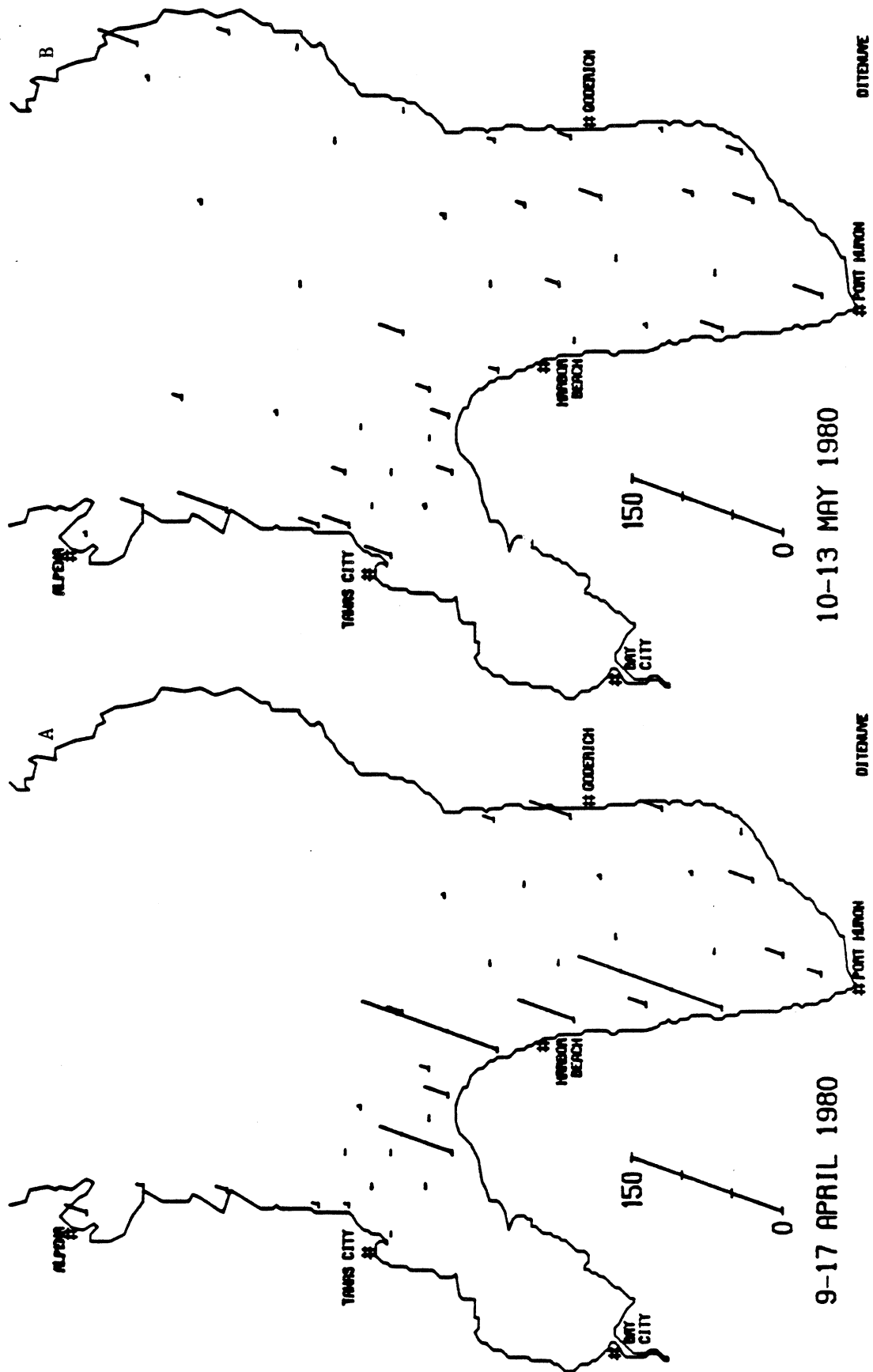


FIG. 18. Distribution of Diatoma tenue var. elongatum.

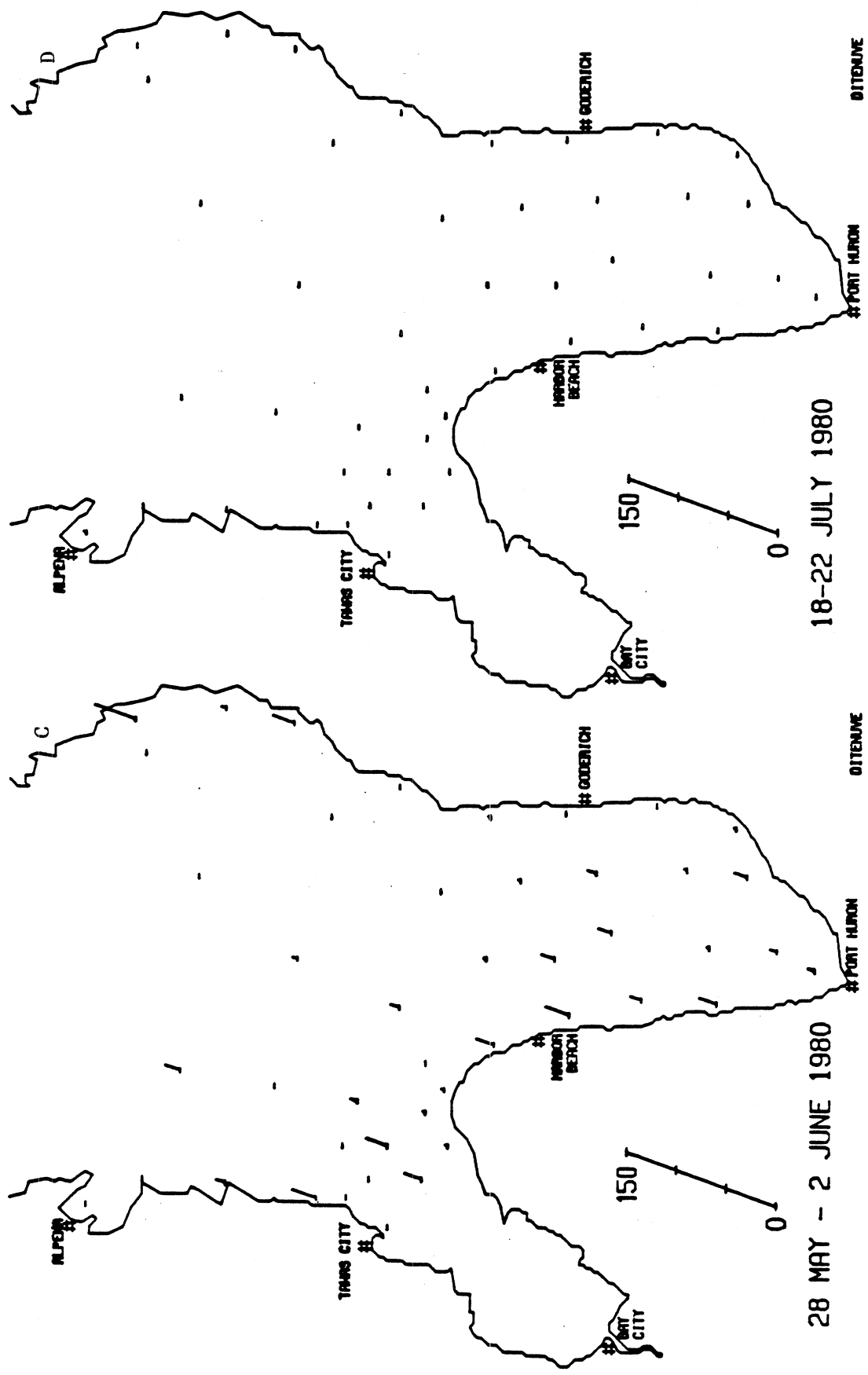


FIG. 18. (continued)

seen in nearshore areas. During June (Fig. 18C), a wide but sporadic distribution was noted. Abundances were relatively low compared to the previous month. During July (Fig. 18D), abundances were severely reduced and Thunder Bay at Alpena supported the only population of this species. No occurrences of D. tenue var. elongatum were observed for the remainder of the cruise season.

#### Fragilaria capucina--

This species of Fragilaria is associated with enriched areas and may become abundant shoreward of the spring thermal bar (Davis et al. 1980). In April (Fig. 19A), it occurred in Saginaw Bay and at a few U.S. nearshore stations in the southern basin. During May (Fig. 19B), slightly increased abundance was seen in outer Saginaw Bay with several occurrences along the Canadian shore in the southern basin. Slightly reduced abundances were noted in June (Fig. 19C), when it was restricted to Saginaw Bay and the nearshore zone in the southern basin. This species was not observed in July. A single station in Saginaw Bay at Tawas City contained this species during September (Fig. 19D). In October (Fig. 19E), it was observed in highest abundance for the year in Saginaw Bay and along the U.S. coastal region in both basins.

#### Fragilaria crotonensis--

This species is cosmopolitan, exhibiting a wide range of tolerance. It is probably the most reported planktonic species of the genus. In April (Fig. 20A), largest abundances were seen along the entire U.S. shoreline and in Saginaw Bay and associated waters. It reached its greatest abundance in the nearshore area south of Goderich (Fig. 20B) in May, although it was widely distributed. During June (Fig. 20C), this population was present along the

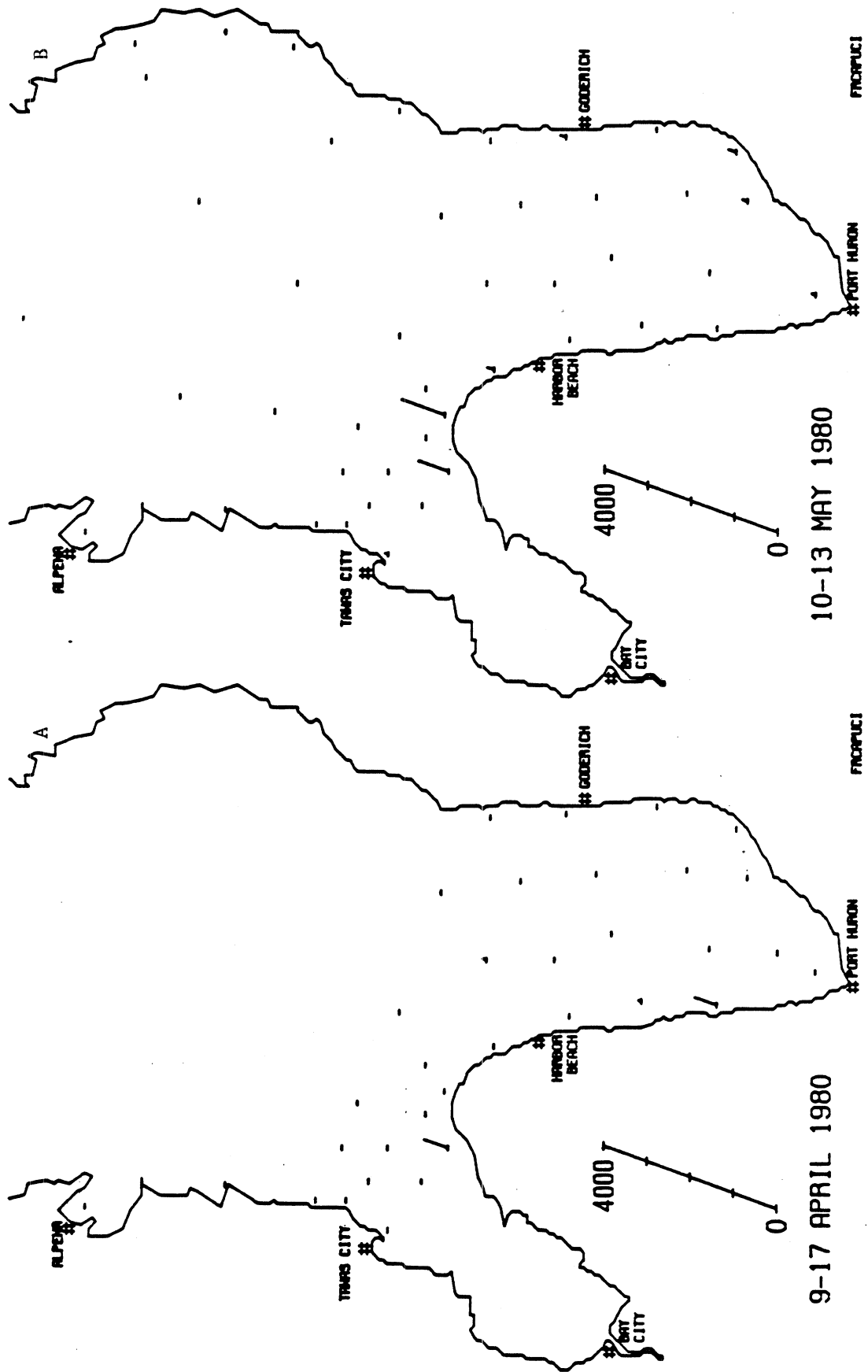


FIG. 19. Distribution of *Fragilaria capucina*.

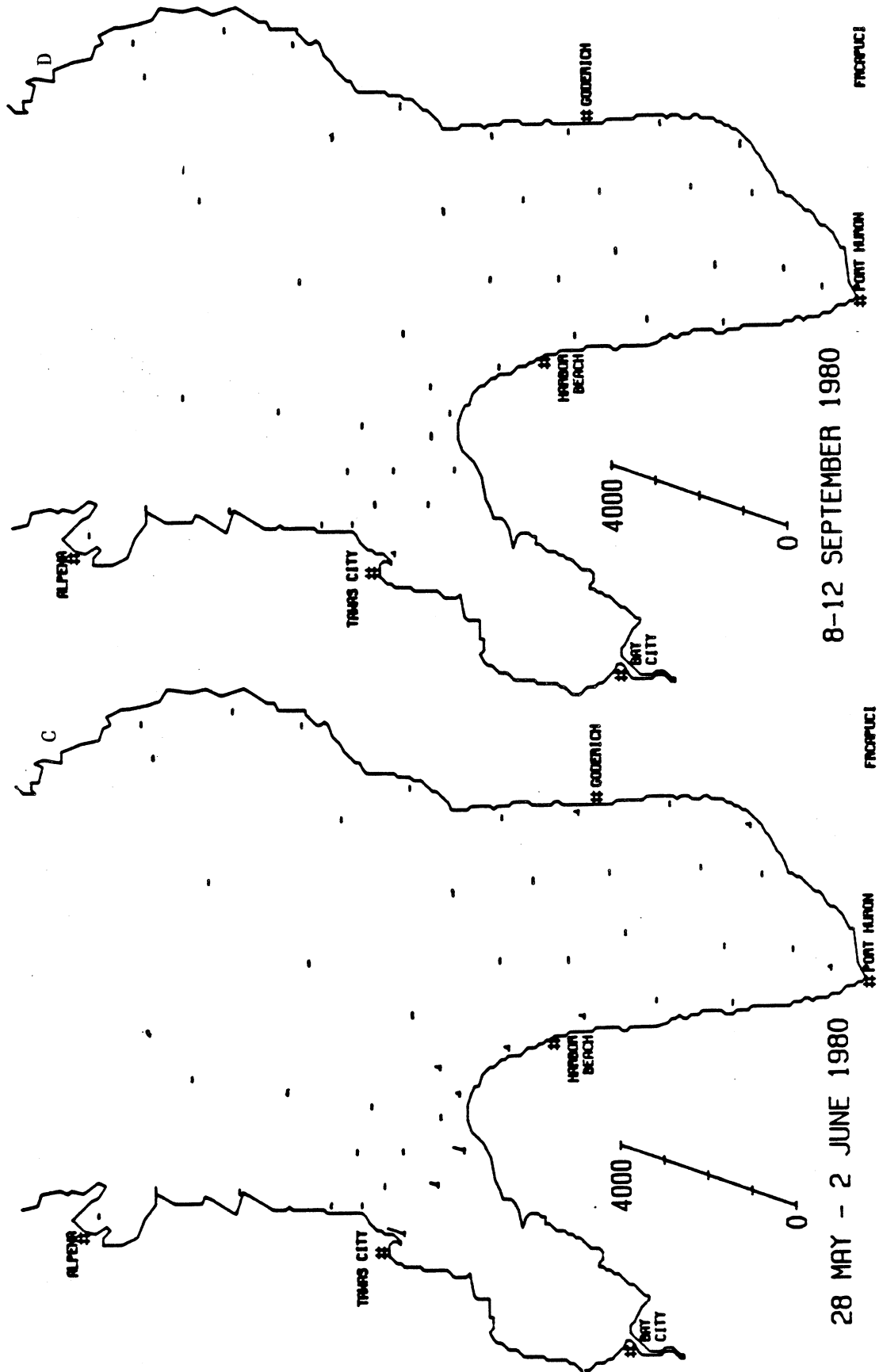


FIG. 19. (continued)

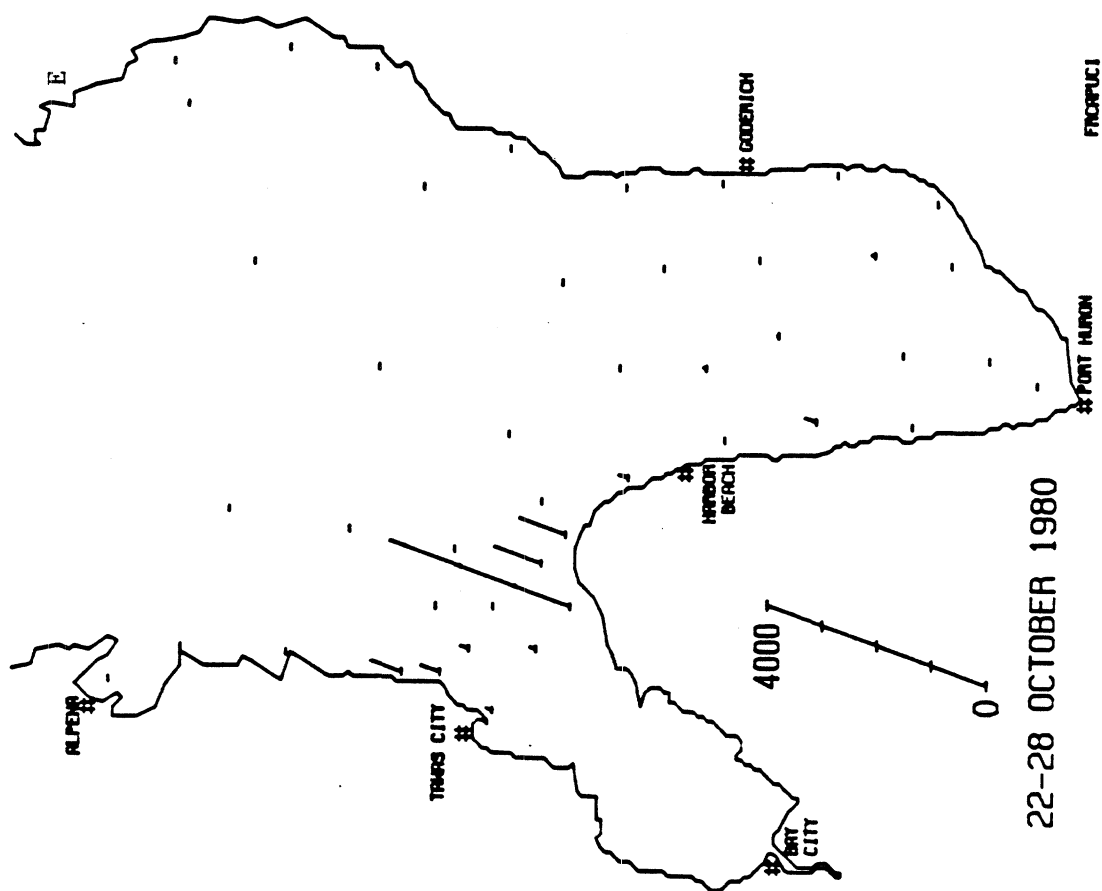


FIG. 19. (continued)

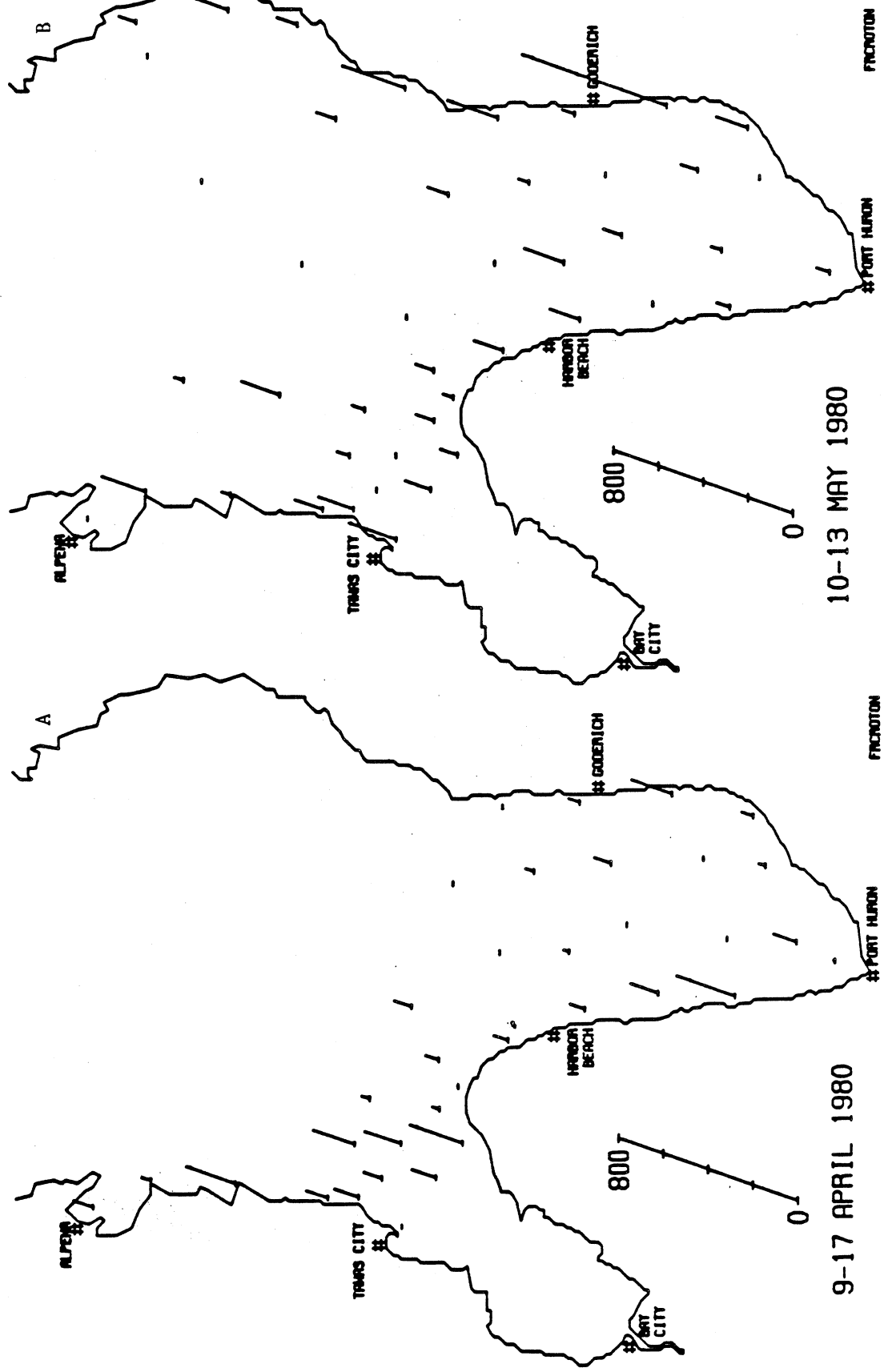


FIG. 20. Distribution of *Fragilaria crotonensis*.

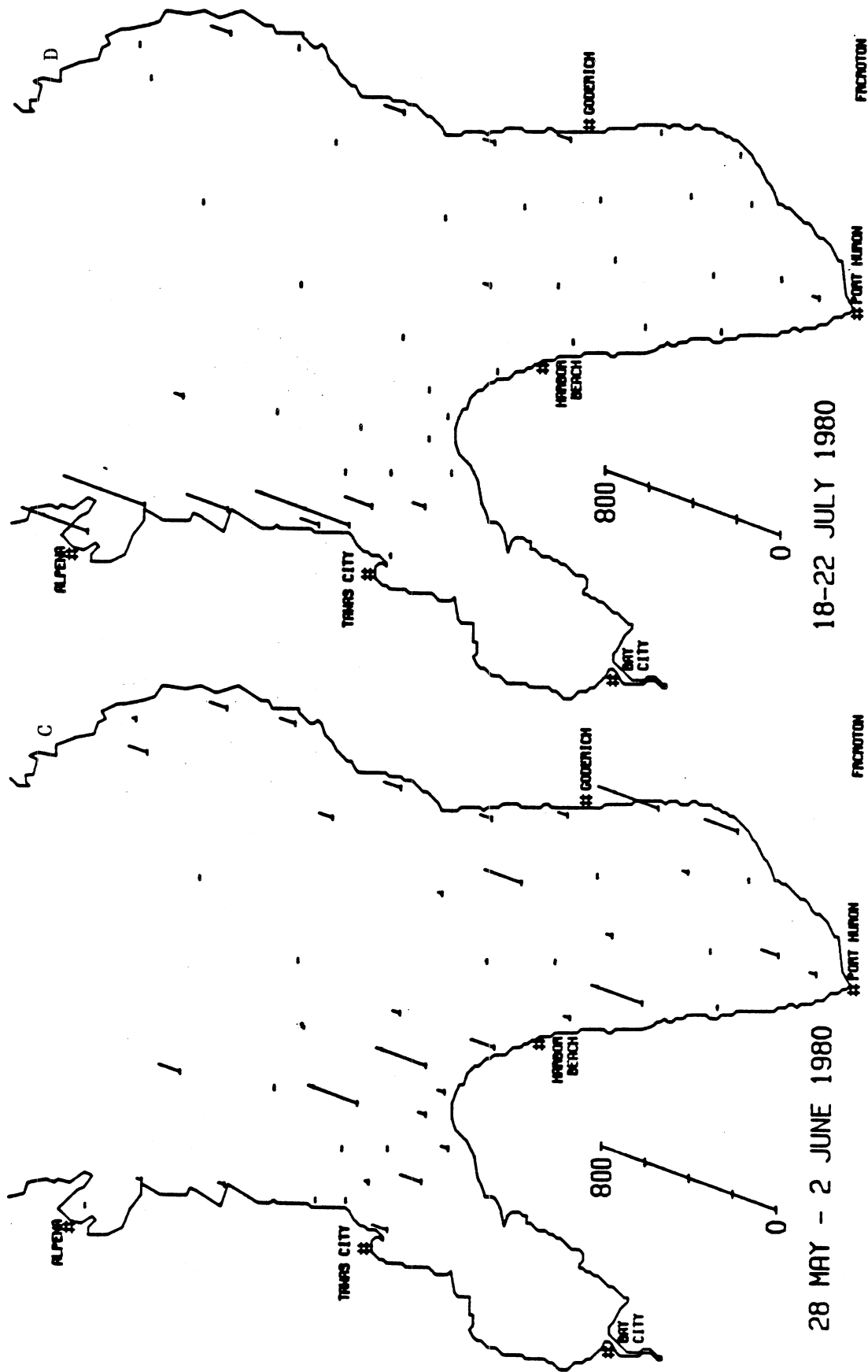


FIG. 20. (continued)

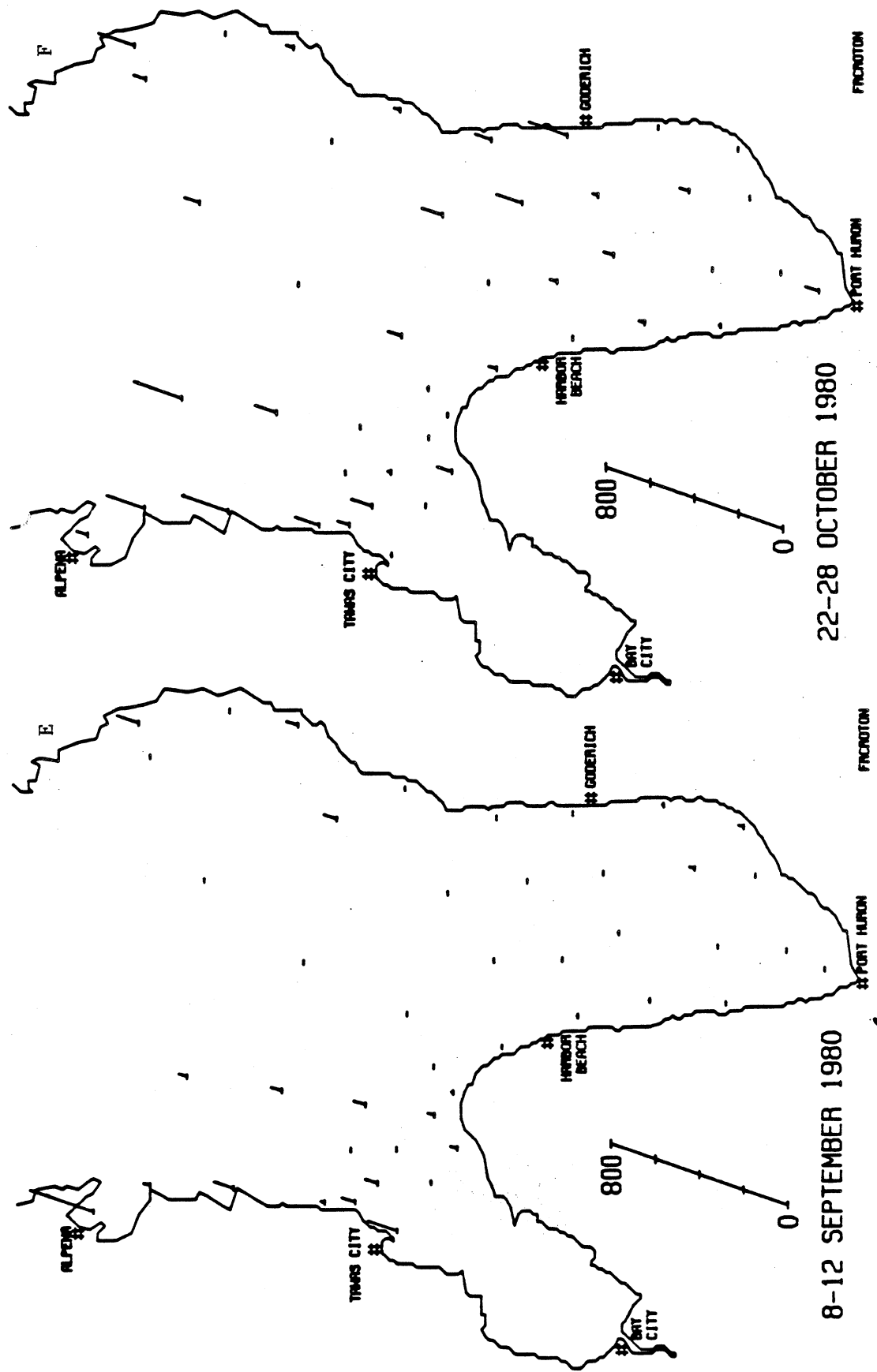


FIG. 20. (continued)

entire Canadian shoreline but in an erratic pattern elsewhere. Large abundances were observed nearshore between Alpena and Tawas City during July (Fig. 20D). It also occurred along the Canadian coastline but was greatly reduced in offshore waters during this sampling period. In September (Fig. 20E), abundances were low throughout the lake, with most occurrences centered in the northwestern sector of the central basin. Abundances were slightly higher in October, with greatest densities again in the northwestern sector of the central basin but distribution was erratic (Fig. 20F).

Fragilaria pinnata--

This species of Fragilaria and its varieties are associated with littoral habitats in the Great Lakes, usually growing in the periphyton or in benthic assemblages. Fairly large abundances were noted along the U.S. coastline and in Saginaw Bay during April (Fig. 21A). In May (Fig. 21B), few occurrences were noted but a large peak was observed in the nearshore zone between Alpena and Tawas City. During June and July (Figs. 21C and 21D) cell numbers were greatly reduced with most occurrences recorded in the southern basin. During September (Fig. 21E), modest abundances were noted in Saginaw Bay and south of the bay. During October (Fig. 21F), large abundances were seen just north of Tawas City, south of Saginaw Bay, and a very large peak at Port Huron.

Melosira granulata alpha-status--

This is a morphologically coarse form of Melosira granulata which is found particularly in disturbed areas of the Great Lakes (Stoermer et al. 1981). This species was a very minor assemblage component in southern Lake Huron. Populations were observed in outer Saginaw Bay and the nearshore zone below Saginaw Bay in April (Fig. 22A). This taxon was not recorded

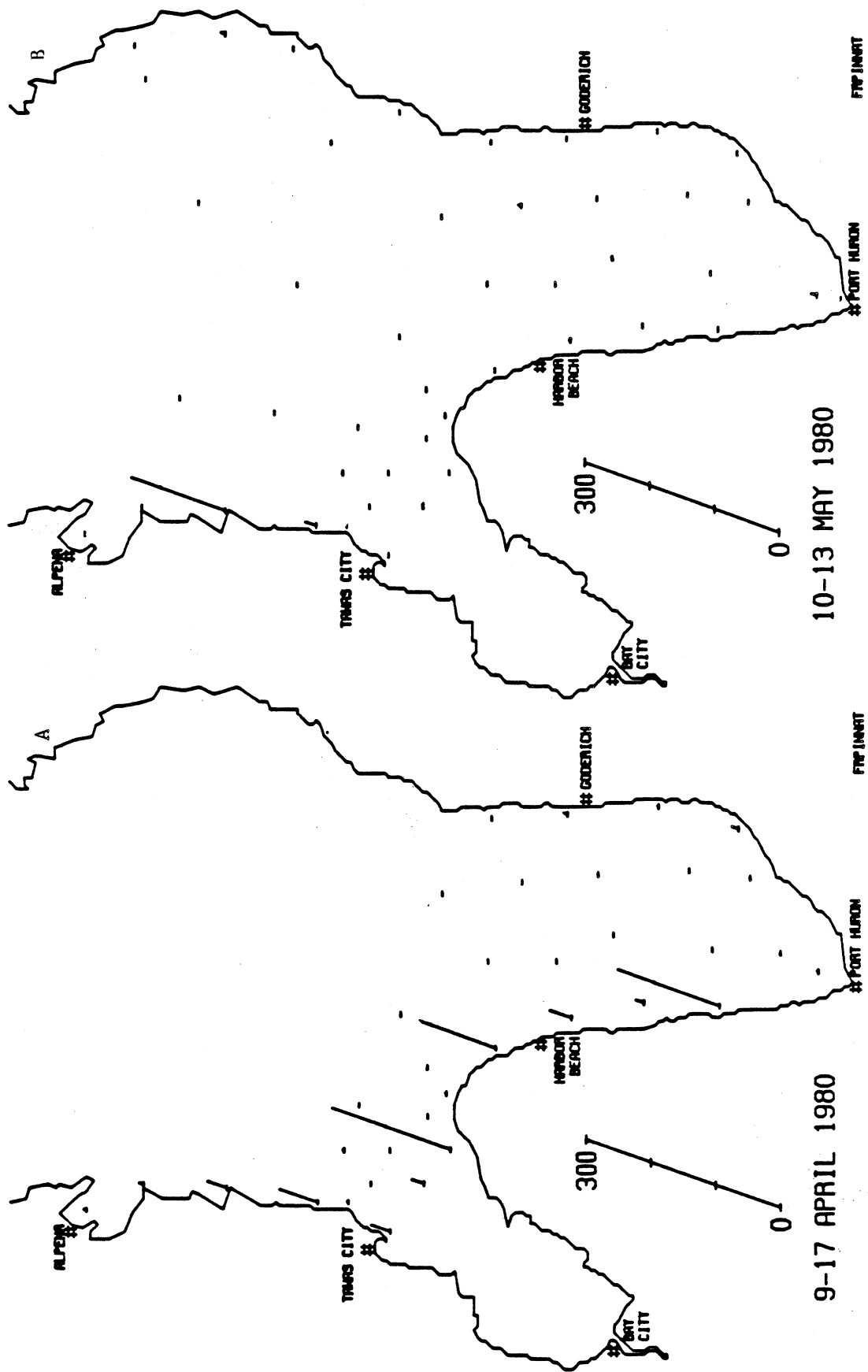


FIG. 21. Distribution of *Fragilaria pinnata*.

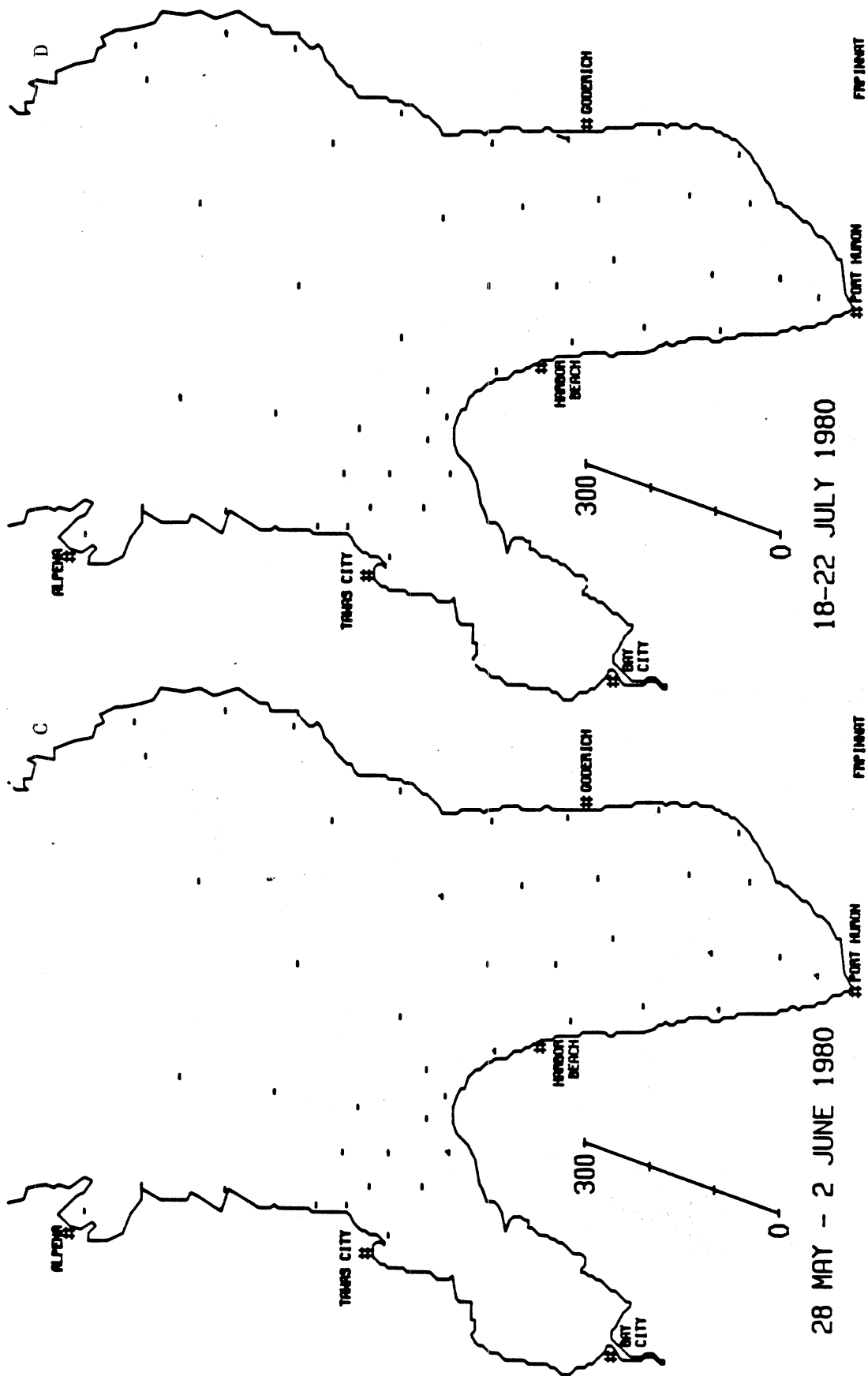


FIG. 21. (continued)

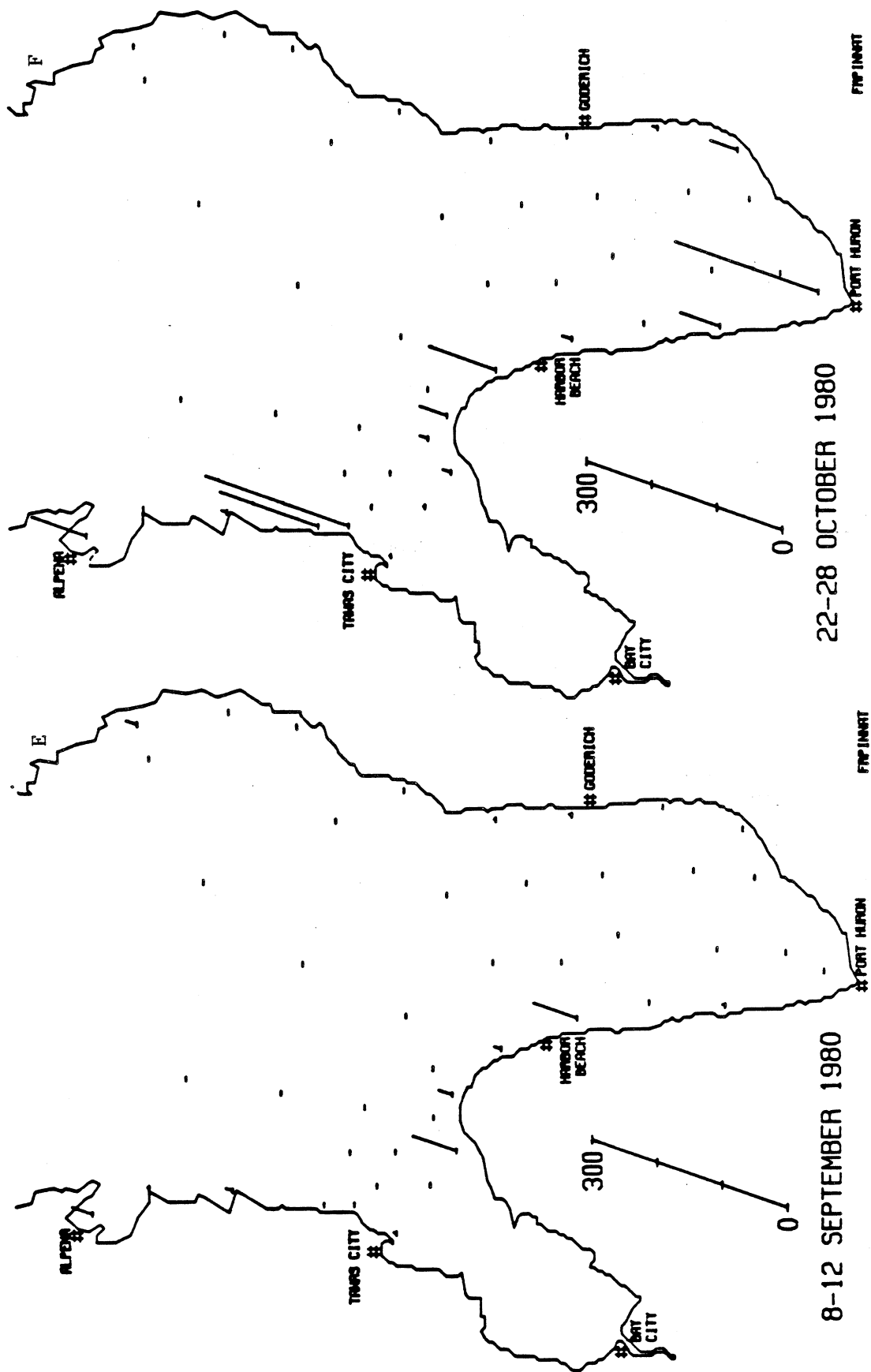


FIG. 21. (continued)

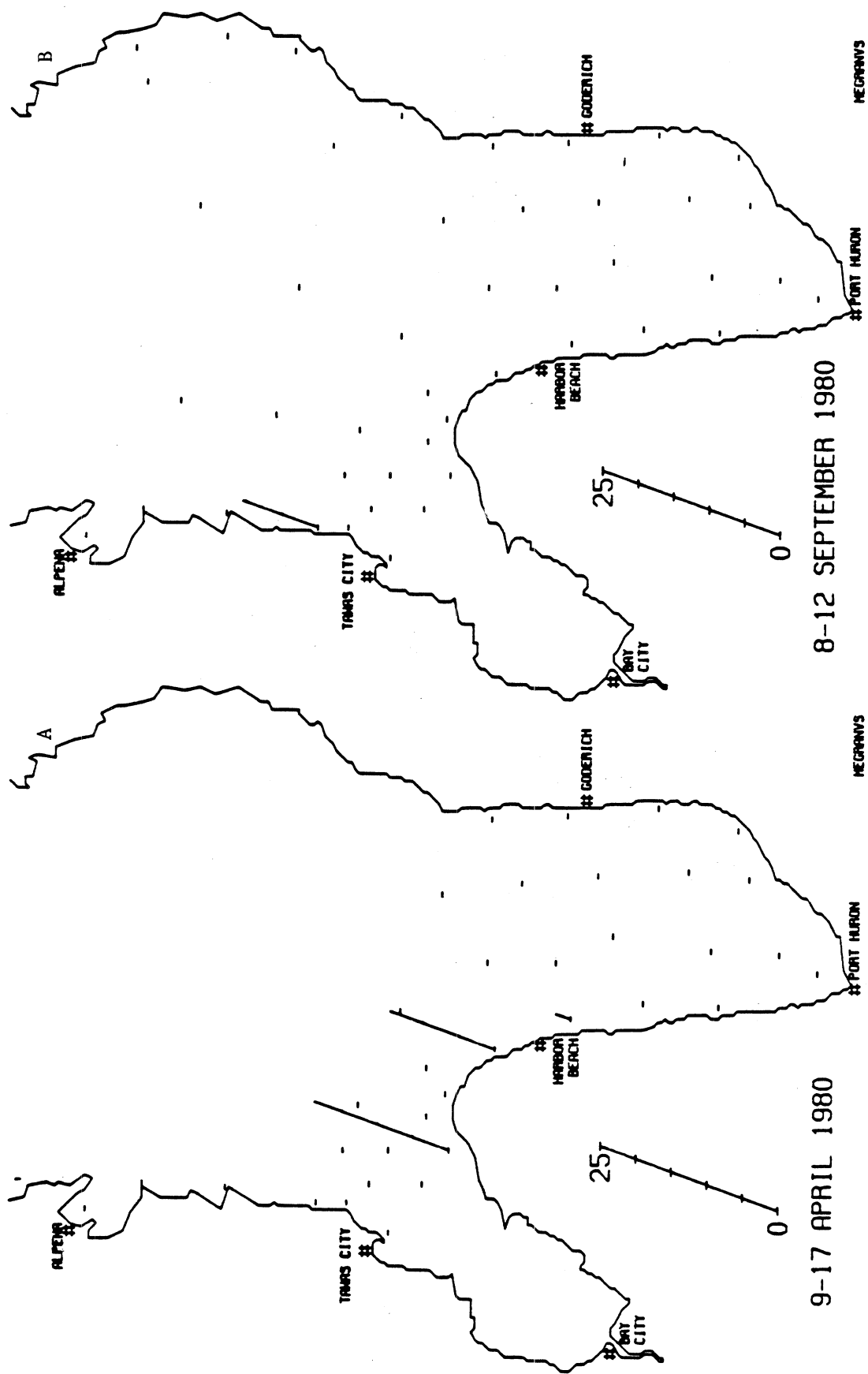


FIG. 22. Distribution of *Melosira granulata* alpha-status.

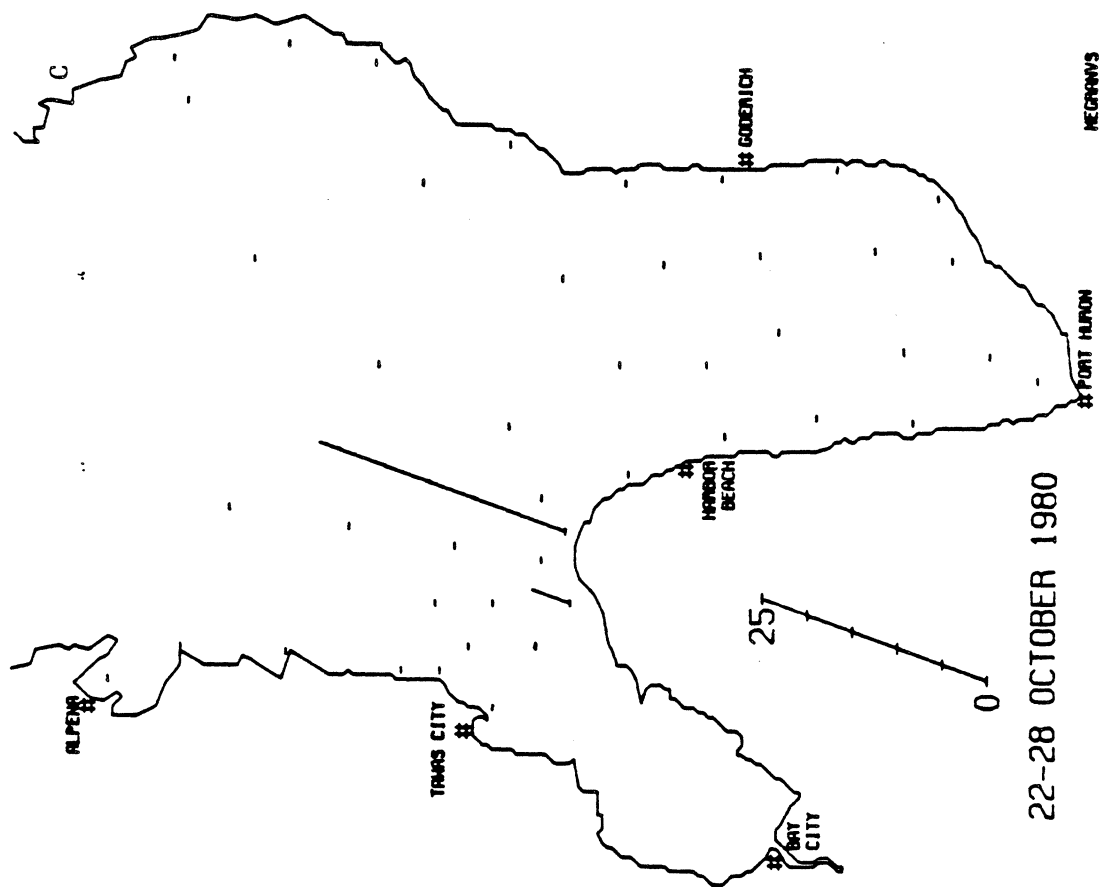


FIG. 22. (continued)

through the remainder of the spring and summer until September (Fig. 22B), when a single occurrence was observed nearshore, north of Tawas City. During October (Fig. 22C), two sites in outer Saginaw Bay supported populations of M. granulata.

#### Melosira islandica--

M. islandica has been reported from all of the Great Lakes and is usually found in widest distribution and highest abundance during the spring (Stoermer et al. 1981). In April (Fig. 23A), highest abundance was seen nearshore, south of Goderich. In general, high cell concentrations were centered in the southern basin with lower abundances in the Saginaw Bay interface waters and northward. During May (Fig. 23B), highest abundances were recorded on the eastern side of the lake, although it was distributed throughout the survey area. During June (Fig. 23C), population occurrence and abundance was centered along the long axis of the study area and on the Canadian shoreline. Reduced and very low abundances were observed for the remainder of the season (Figs. 23D and 23E).

#### Nitzschia acicularis--

Unlike most species of this genus, N. acicularis may be observed in the euplankton, particularly during the spring months. During April (Fig. 24A), it was observed at its highest abundance for the season with greatest abundances along the southern U.S. coastline. In May (Fig. 24B), it was widely distributed but at reduced abundances. Highest abundances for May were recorded for the nearshore zones of the southern basin. Conversely, in June (Fig. 24C), highest abundances were observed in the offshore waters of the southern basin. During July and September (Figs. 24D and 24E), very few

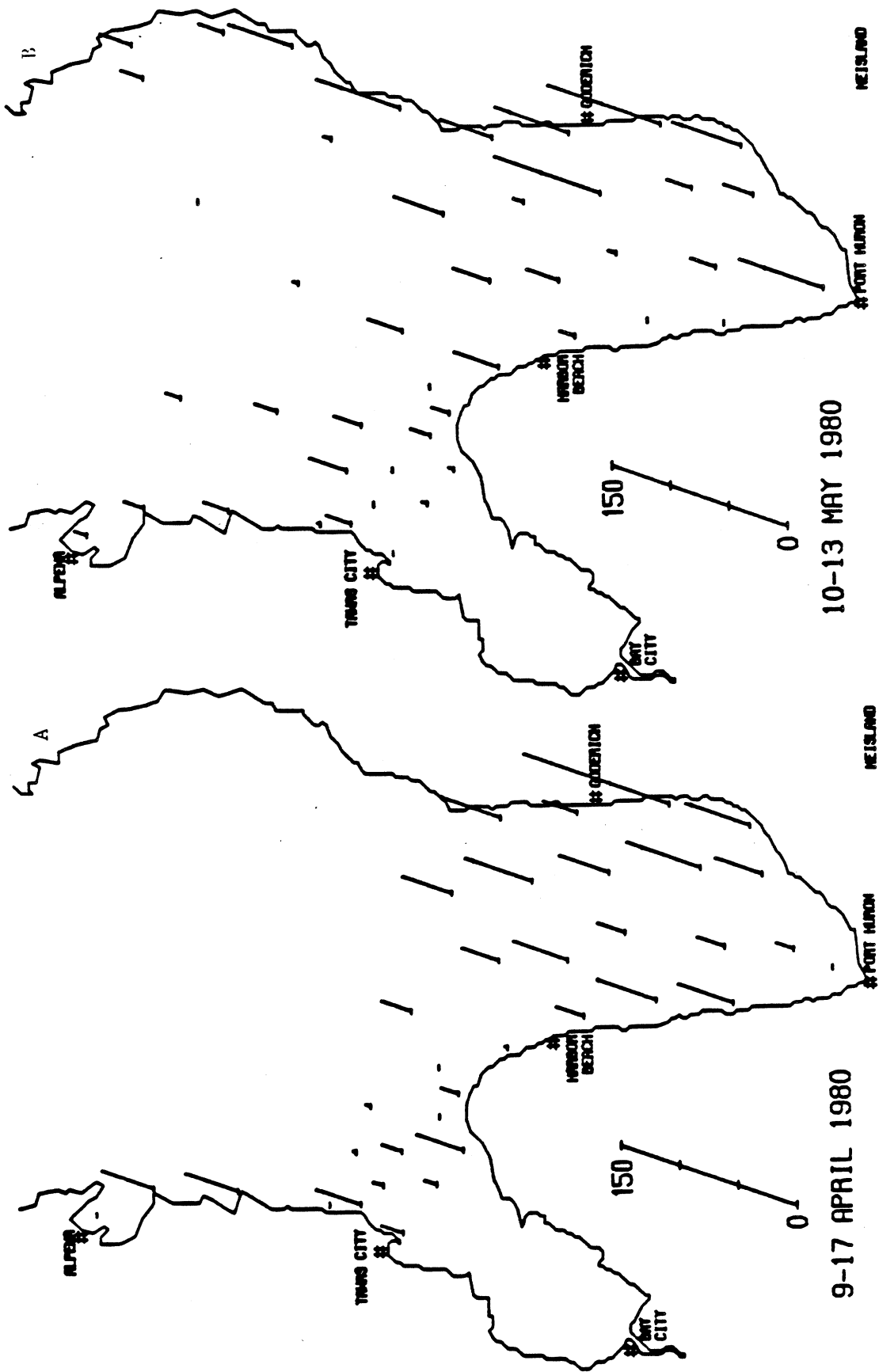


FIG. 23. Distribution of *Melosira islandica*.

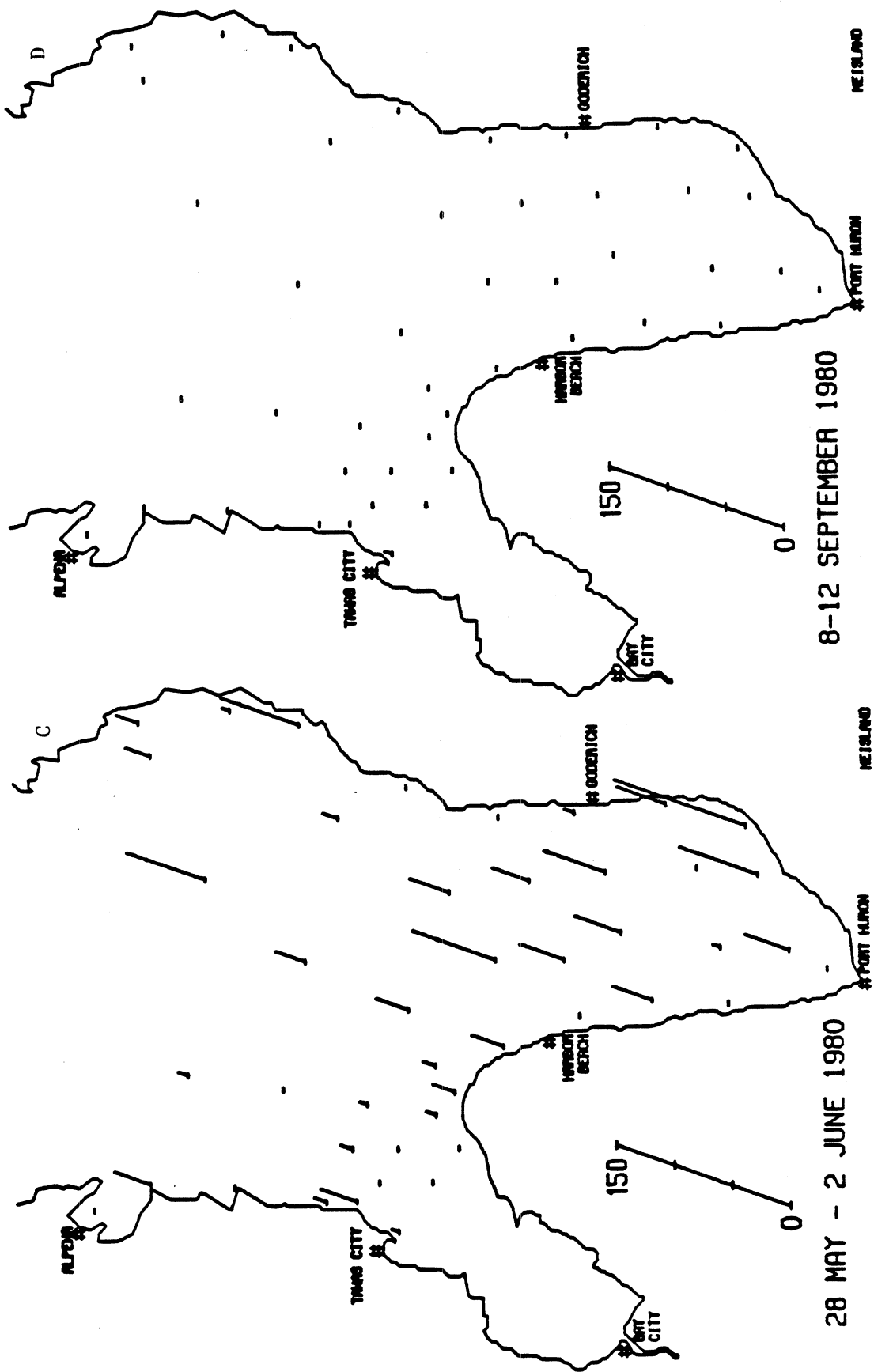


FIG. 23. (continued)

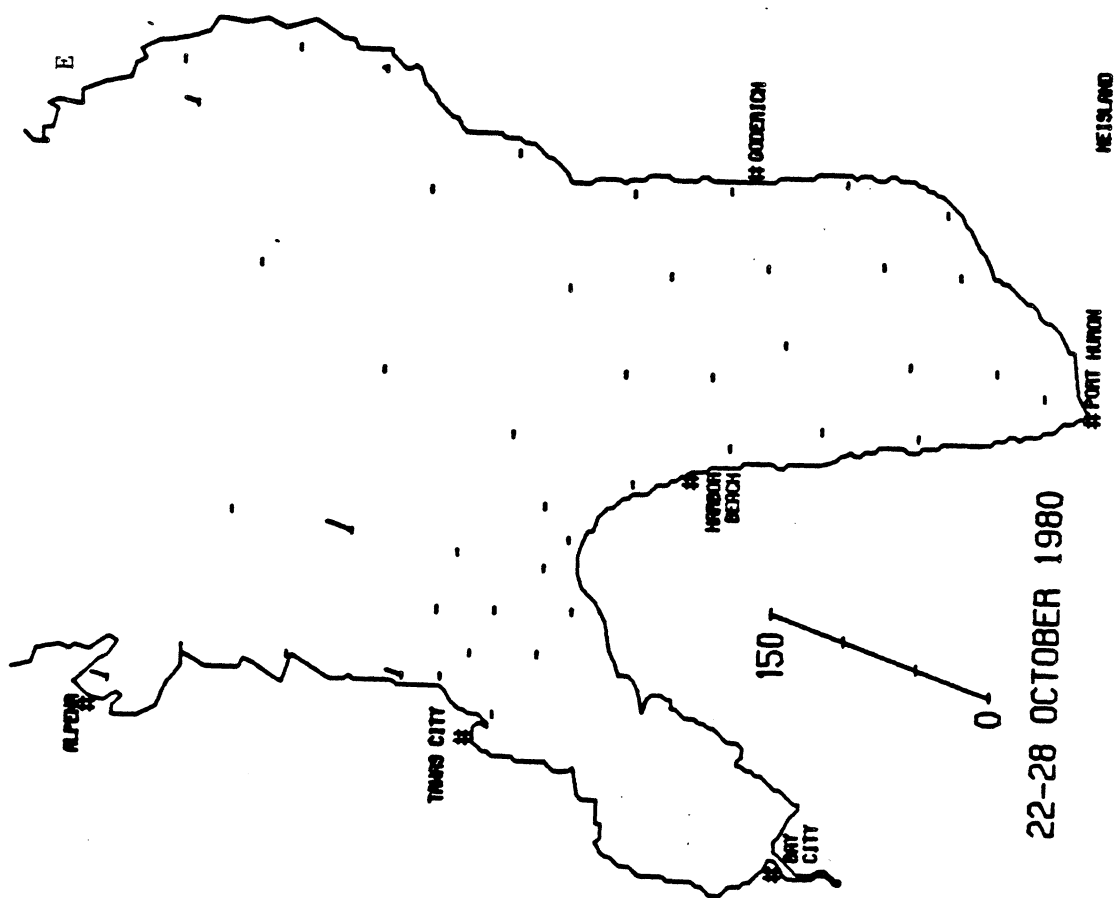


FIG. 23. (continued)

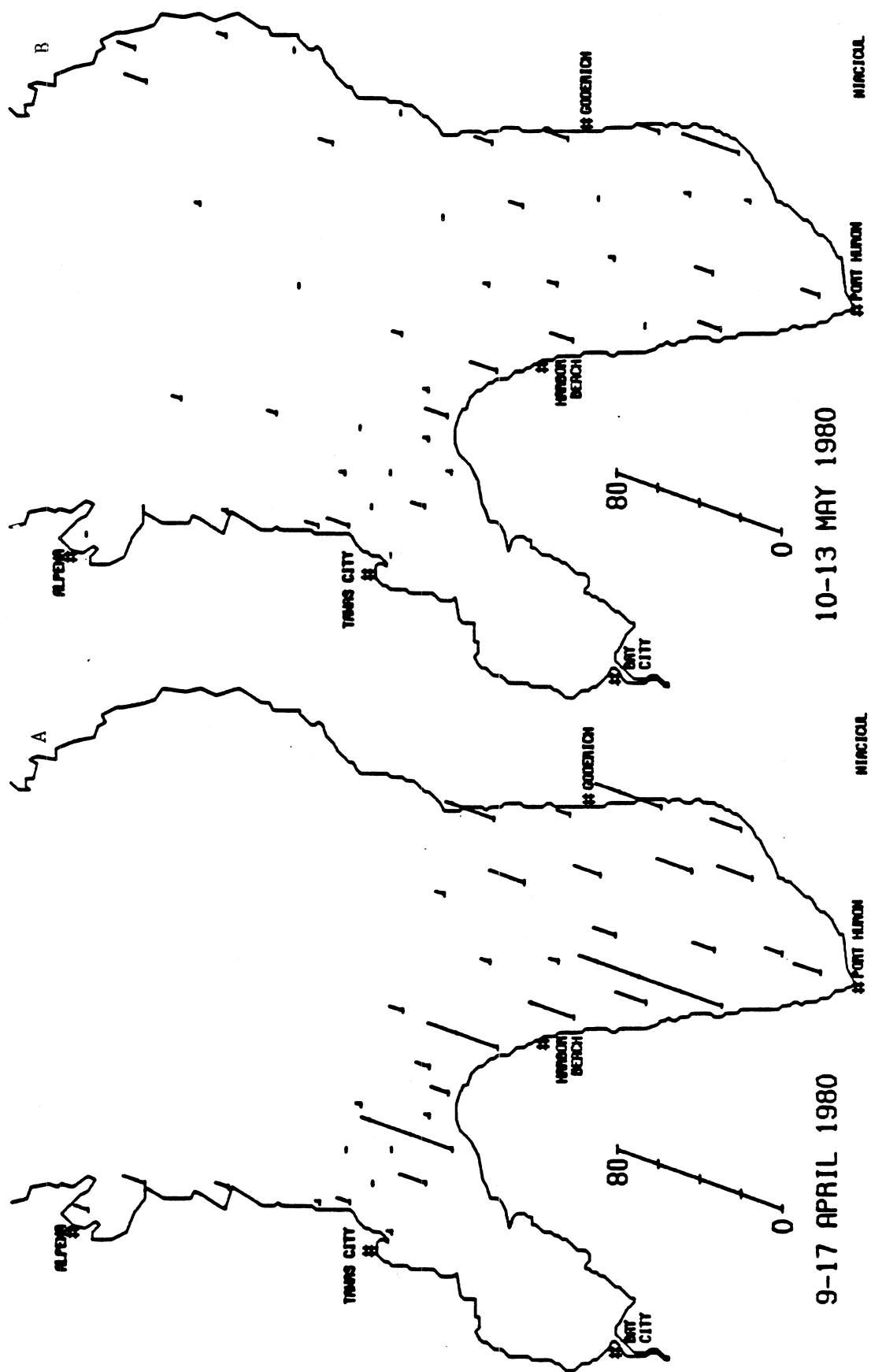


FIG. 24. Distribution of *Nitzschia acicularis*.

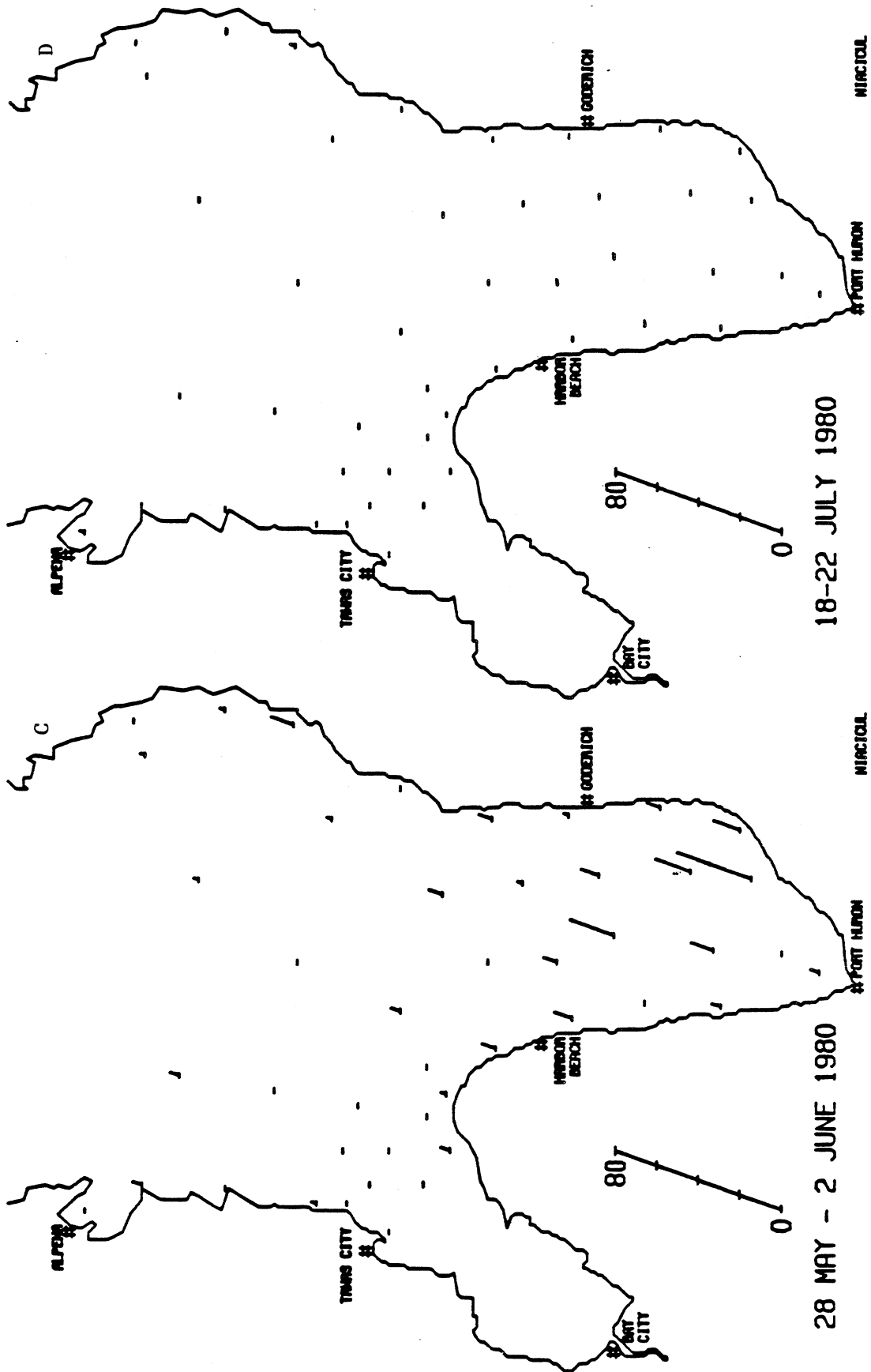


FIG. 24. (continued)

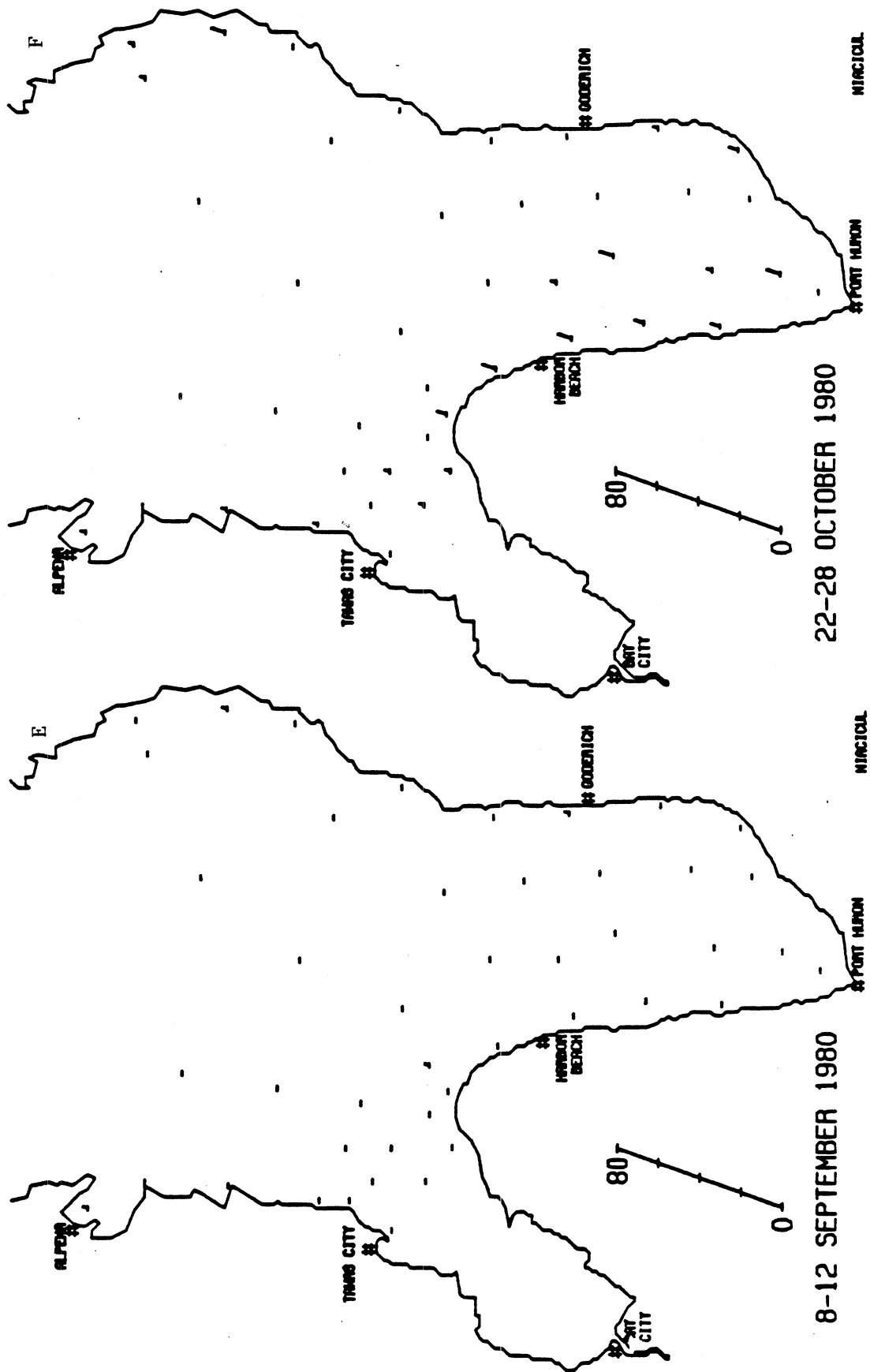


FIG. 24. (continued)

occurrences at low abundances were observed. In October (Fig. 24F), low abundances were recorded along the entire U.S. coastline and Saginaw Bay area.

Nitzschia dissipata--

This taxon is commonly observed in littoral zones, but does occur, as in this study, in offshore waters. In April (Fig. 25A), it occurred over the study area with greatest numbers in nearshore zones. In May (Fig. 25B), it showed comparatively fewer occurrences and was abundant in the offshore waters, especially in the central basin. During June (Fig. 25C), it was most abundant in the southern basin but in an erratic pattern. This species was not present during July. In September and October (Figs. 25D and 25E), it occurred at only a few stations, but in October, showed its single largest abundance, north of the bay.

Rhizosolenia eriensis--

This lightly silicified, delicate diatom species is commonly reported from the offshore waters during the spring in the upper Great Lakes, but it may be influenced by the thermal bar. It was originally described from tap water samples from Lake Erie (Smith 1878). During April (Fig. 26A), it was uniformly distributed over the study area in low abundances. Increased standing crops were observed in May (Fig. 26B) with highest abundances in the Canadian nearshore zone. During June (Fig. 26C), it was present throughout the entire study area with elevated abundances again along the Canadian coastline. Decreased occurrences were seen in July (Fig. 26D) with populations being restricted to the central basin. Few occurrences were recorded for September (Fig. 26E), with no apparent distributional trend.

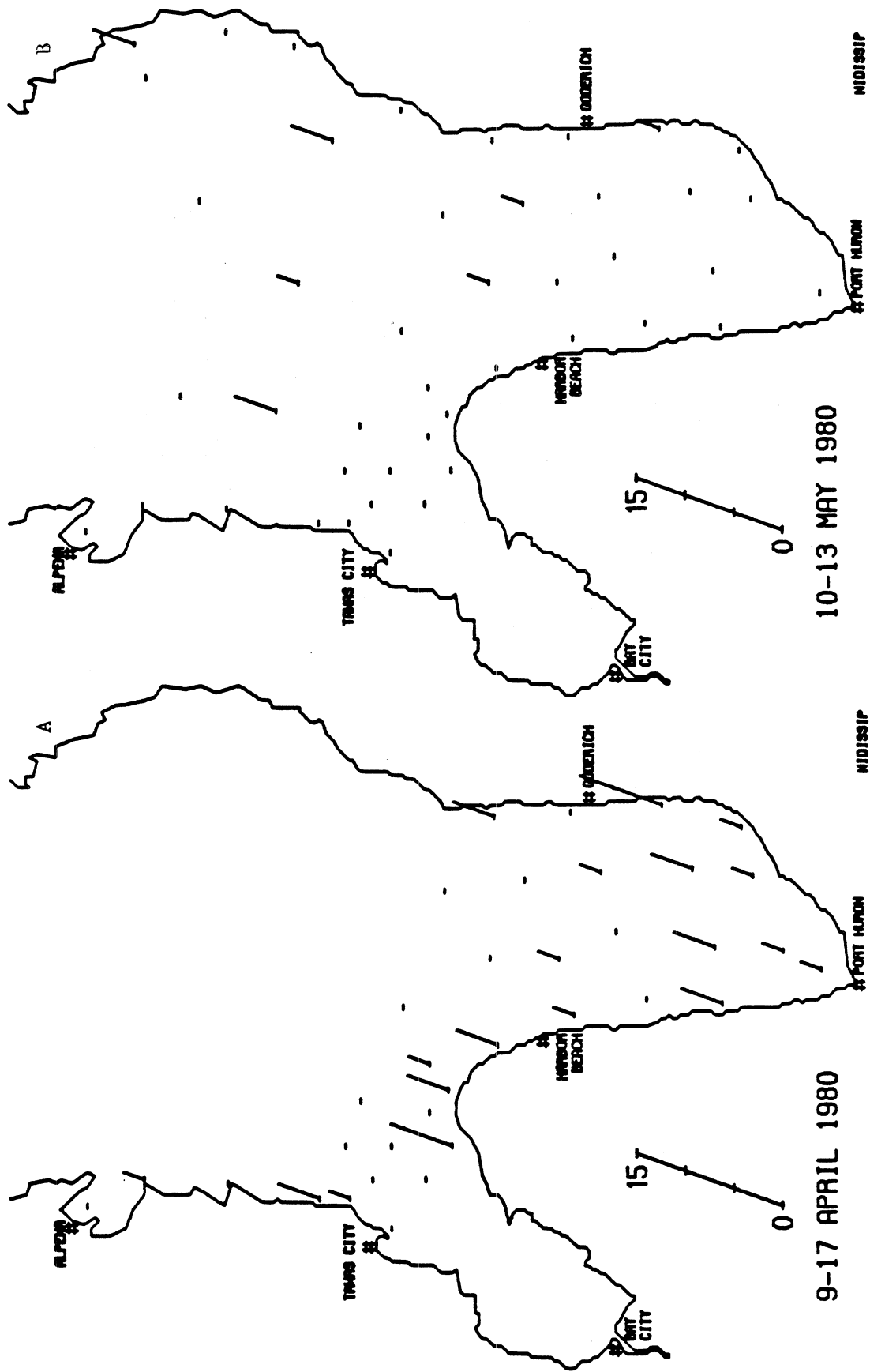


FIG. 25. Distribution of *Nitzschia dissipata*.

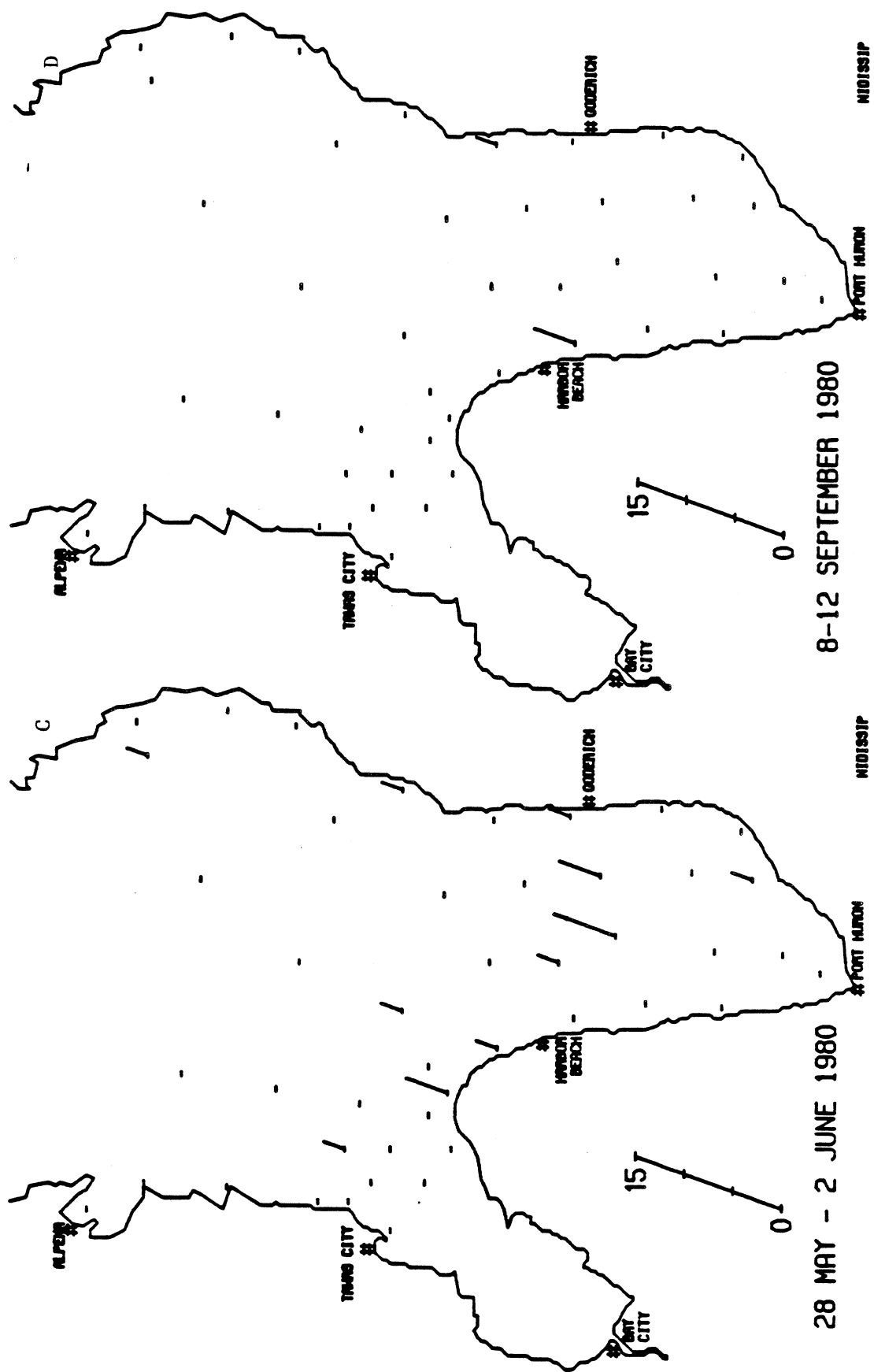


FIG. 25. (continued)

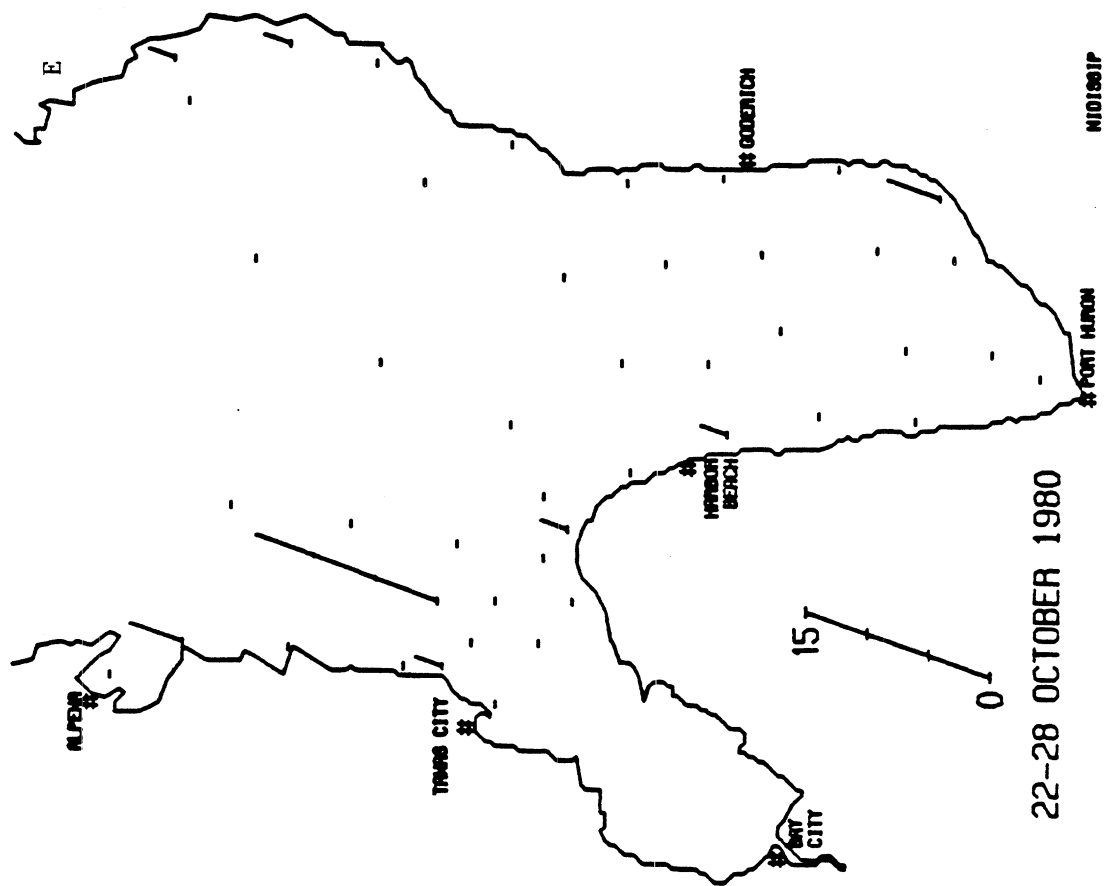


FIG. 25. (continued)

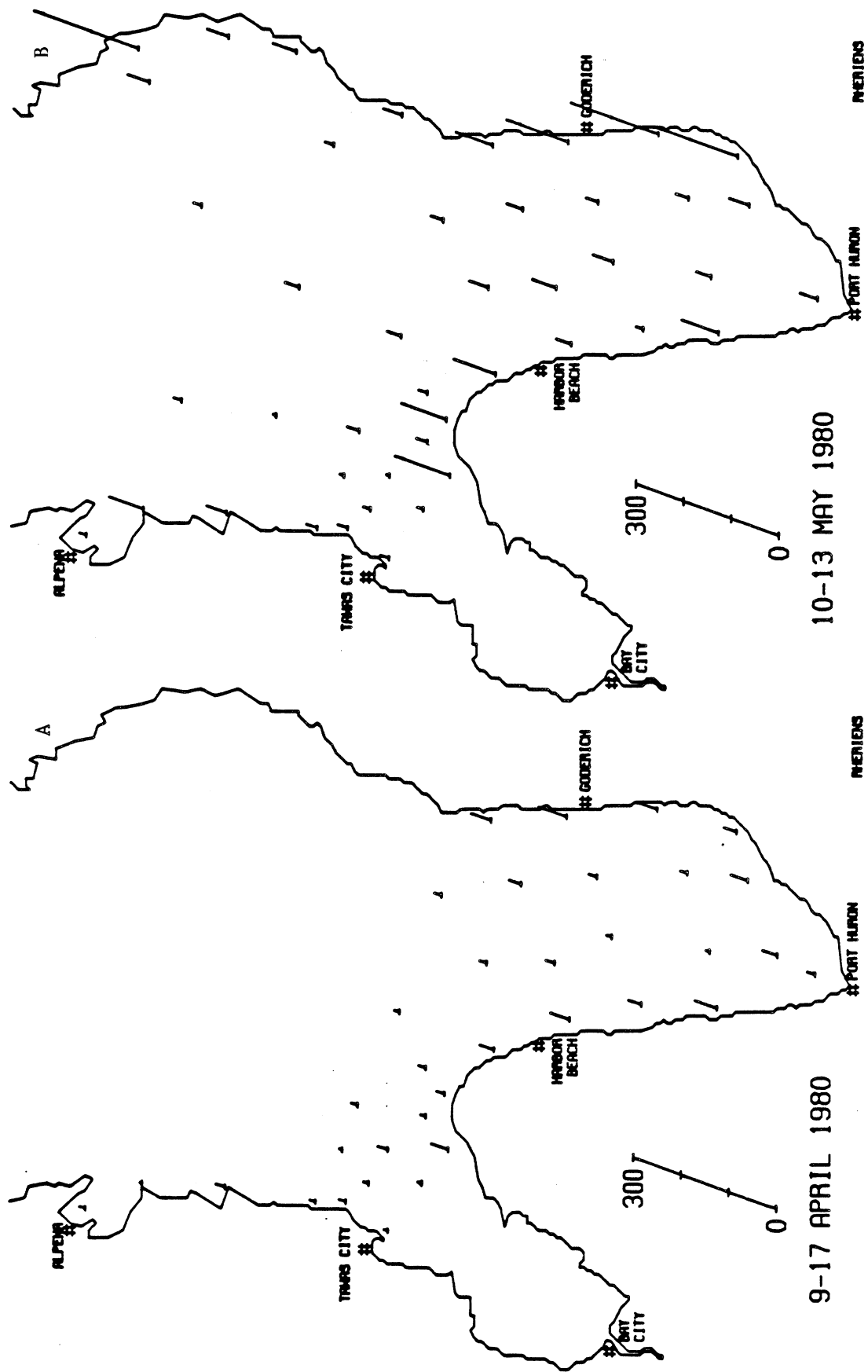


FIG. 26. Distribution of *Rhizosolenia eriensis*.

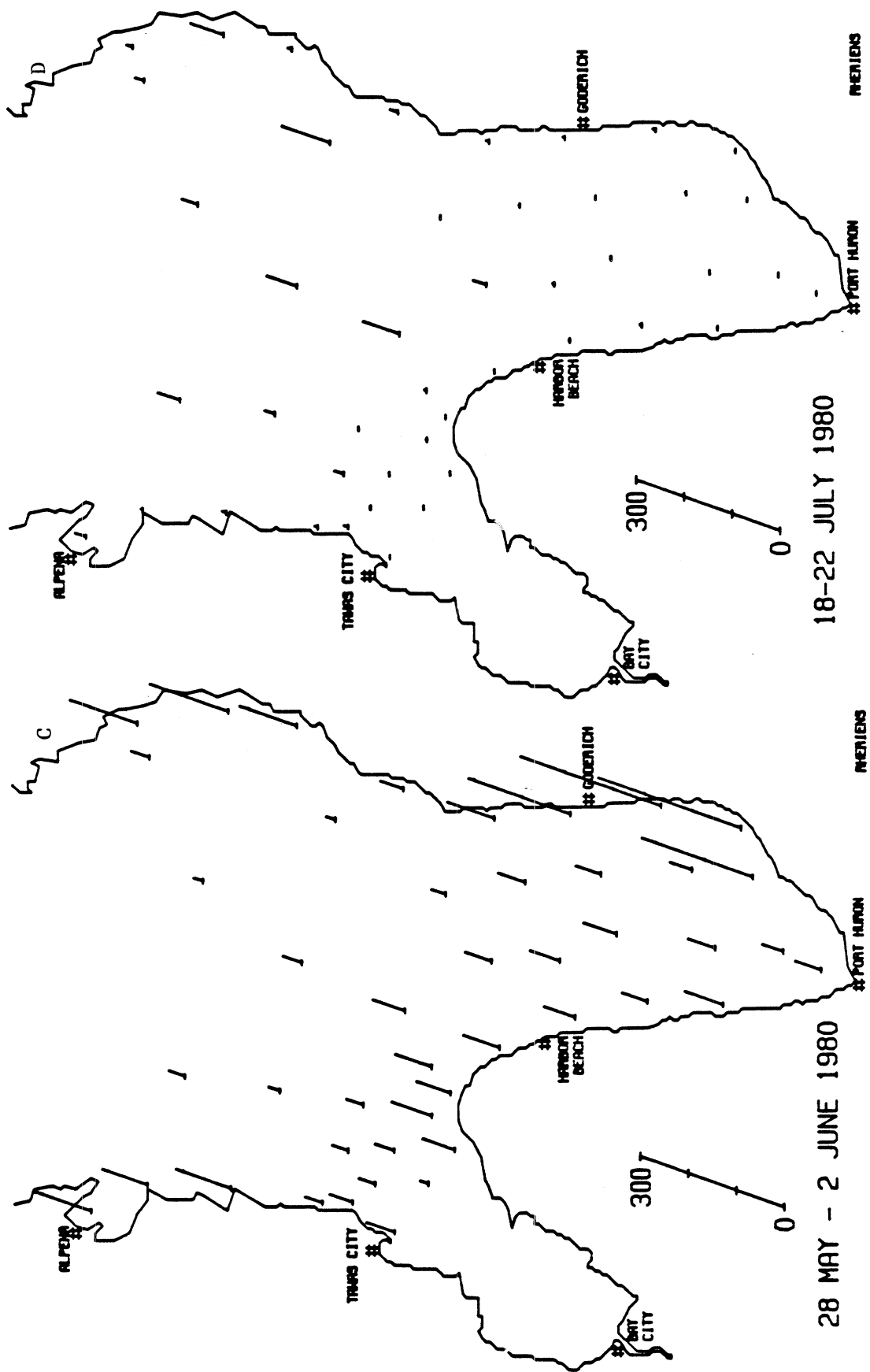


FIG. 26. (continued)

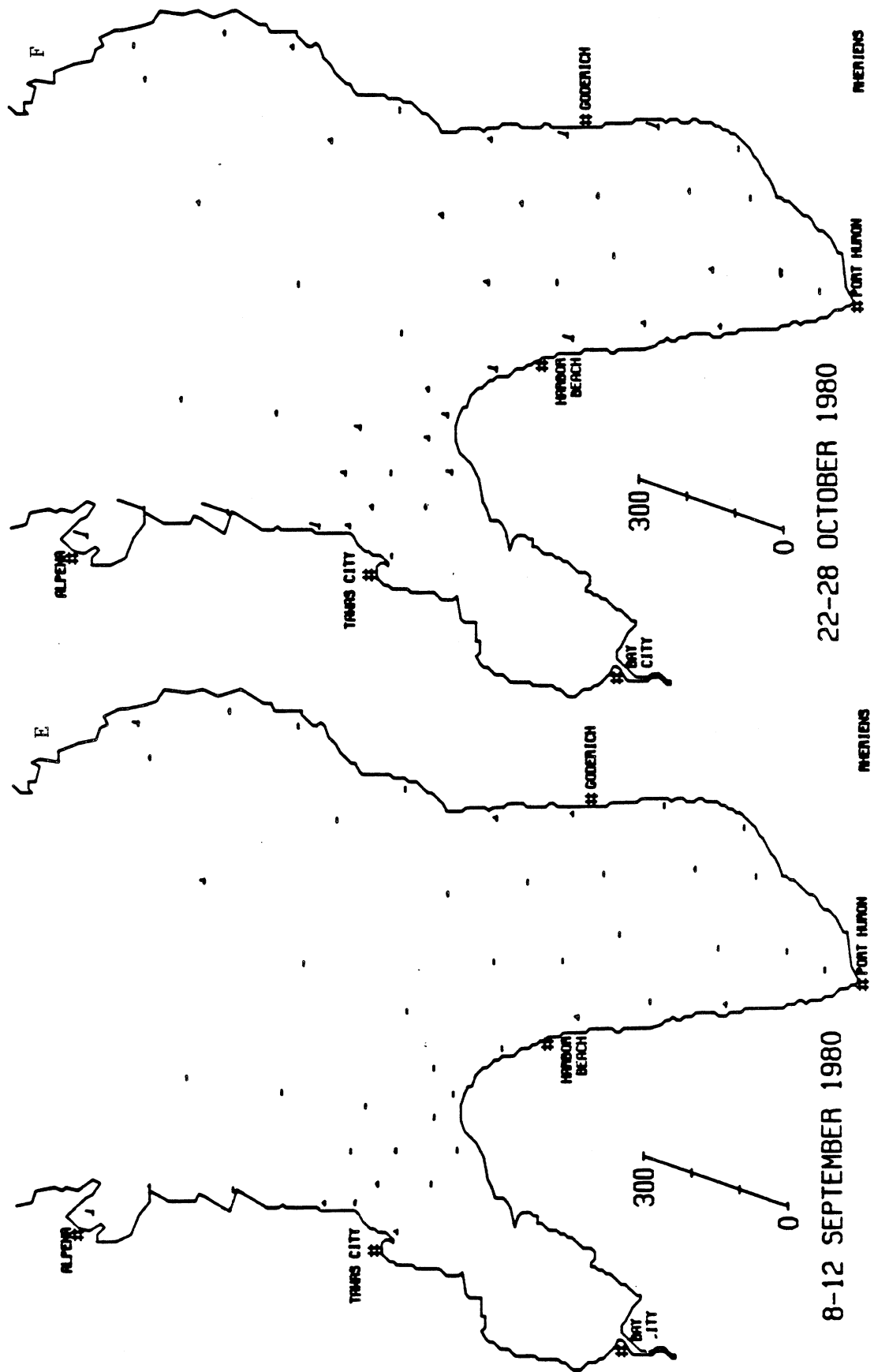


FIG. 26. (continued)

During October (Fig. 26F), very low cell numbers were seen over most areas of the lake with highest values recorded south of Alpena.

#### Rhizosolenia gracilis--

As does the member of this genus just discussed, R. gracilis appears in greatest abundance in the spring but may respond more than R. eriensis to slightly enriched conditions (Nicholls et al. 1977b). It was also originally described from Lake Erie by Smith (1882). Widest occurrence of this taxon was observed in April (Fig. 27A) with largest values being recorded for the nearshore zones around the southern basin. In May (Fig. 27B), its distribution was reduced but reached its highest single abundance nearshore, south of Goderich. Populations were also observed in low abundance, nearshore between Alpena and Tawas City. A few occurrences at low abundance were observed in June and October (Figs. 27C and 27D).

#### Stephanodiscus alpinus--

In the Great Lakes, this species reaches its greatest abundance during the spring months. This species had its greatest number of occurrences in April (Fig. 28A). It was erratically distributed through the southern basin but its single largest concentration for the year occurred in the nearshore zone between Harbor Beach and Port Huron. During May (Fig. 28B), it was observed in outer Saginaw Bay and in the Canadian nearshore zone in the southern basin. In June (Fig. 28C), it was restricted to the U.S. coastline and outer Saginaw Bay, exhibiting low abundances. During July and September (Figs. 28D and 28E), a few occurrences were recorded in the nearshore zones of the central basin. In October (Fig. 28F), very low abundances were seen near outer Saginaw Bay, Tawas City, and the lower southern basin.

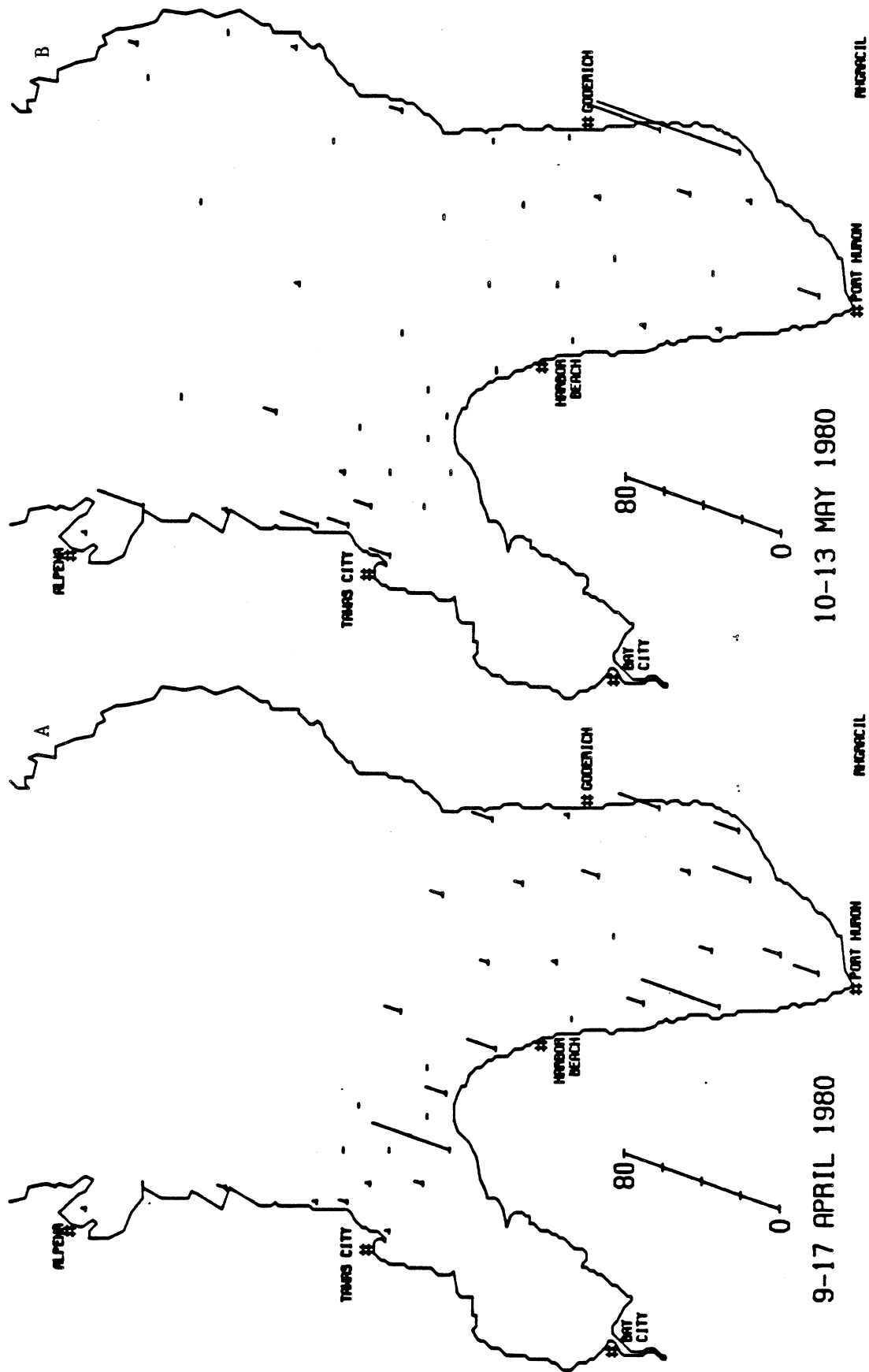


FIG. 27. Distribution of *Rhizosolenia gracilllis*.

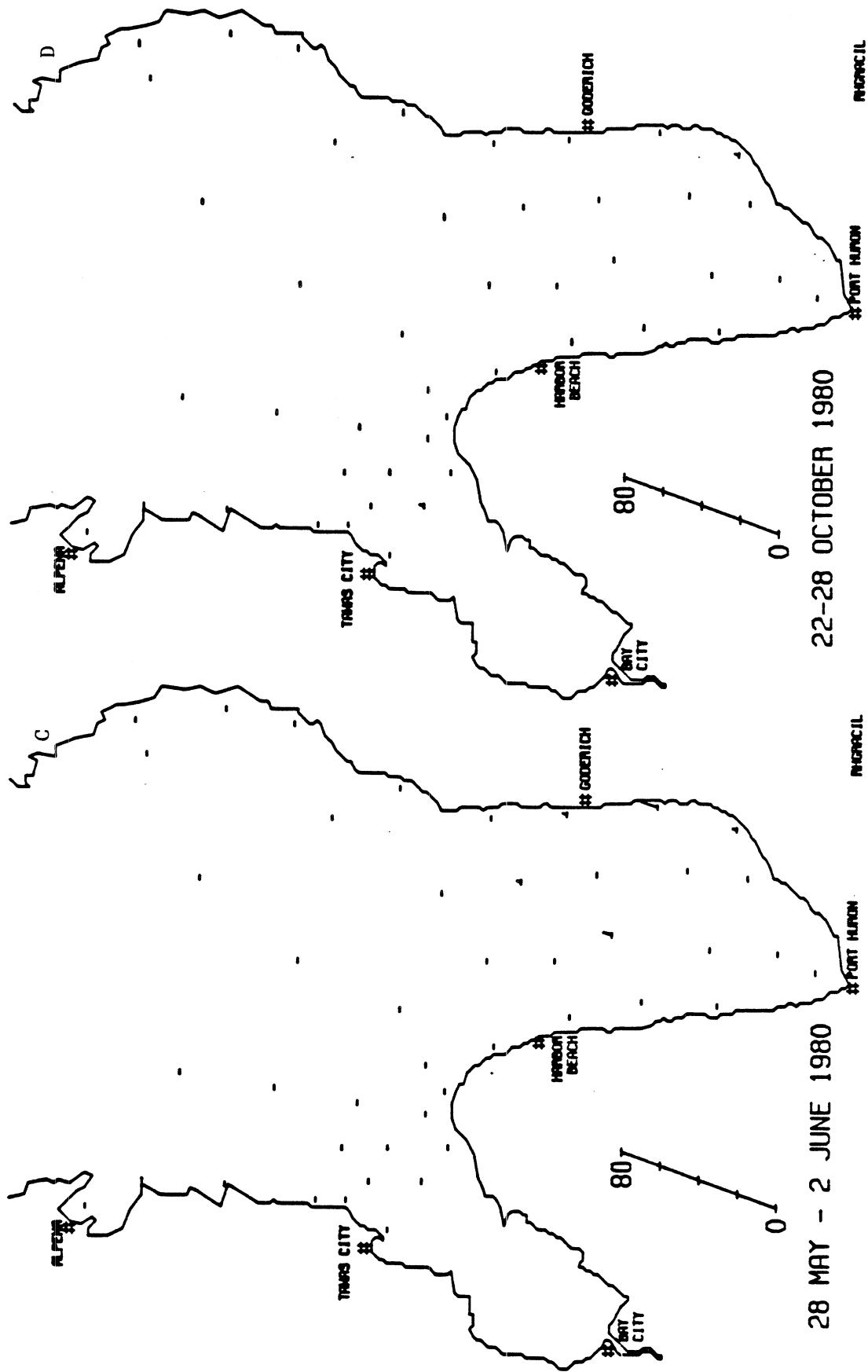


FIG. 27. (continued)

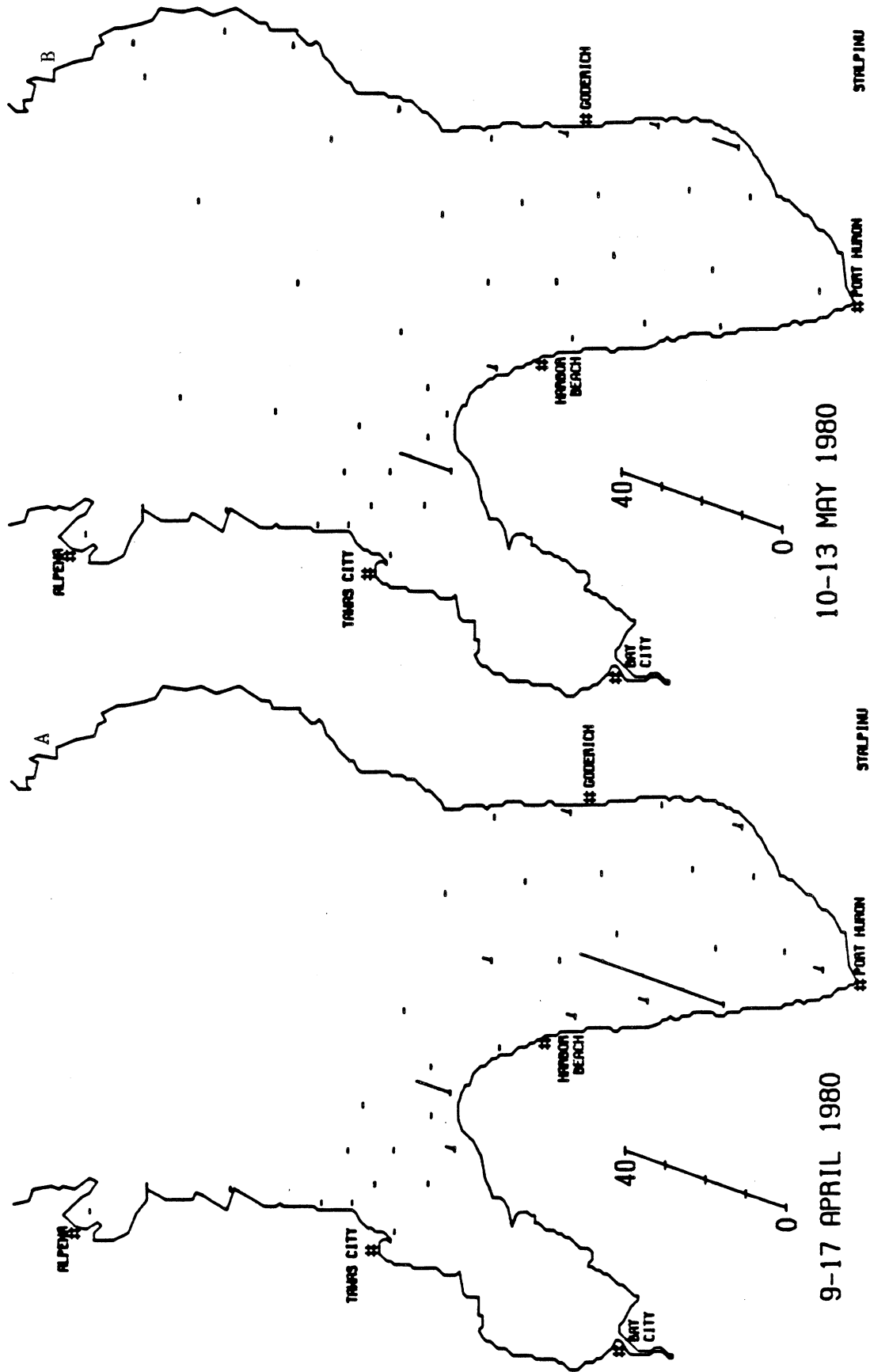


FIG. 28. Distribution of Stephanodiscus alpinus.

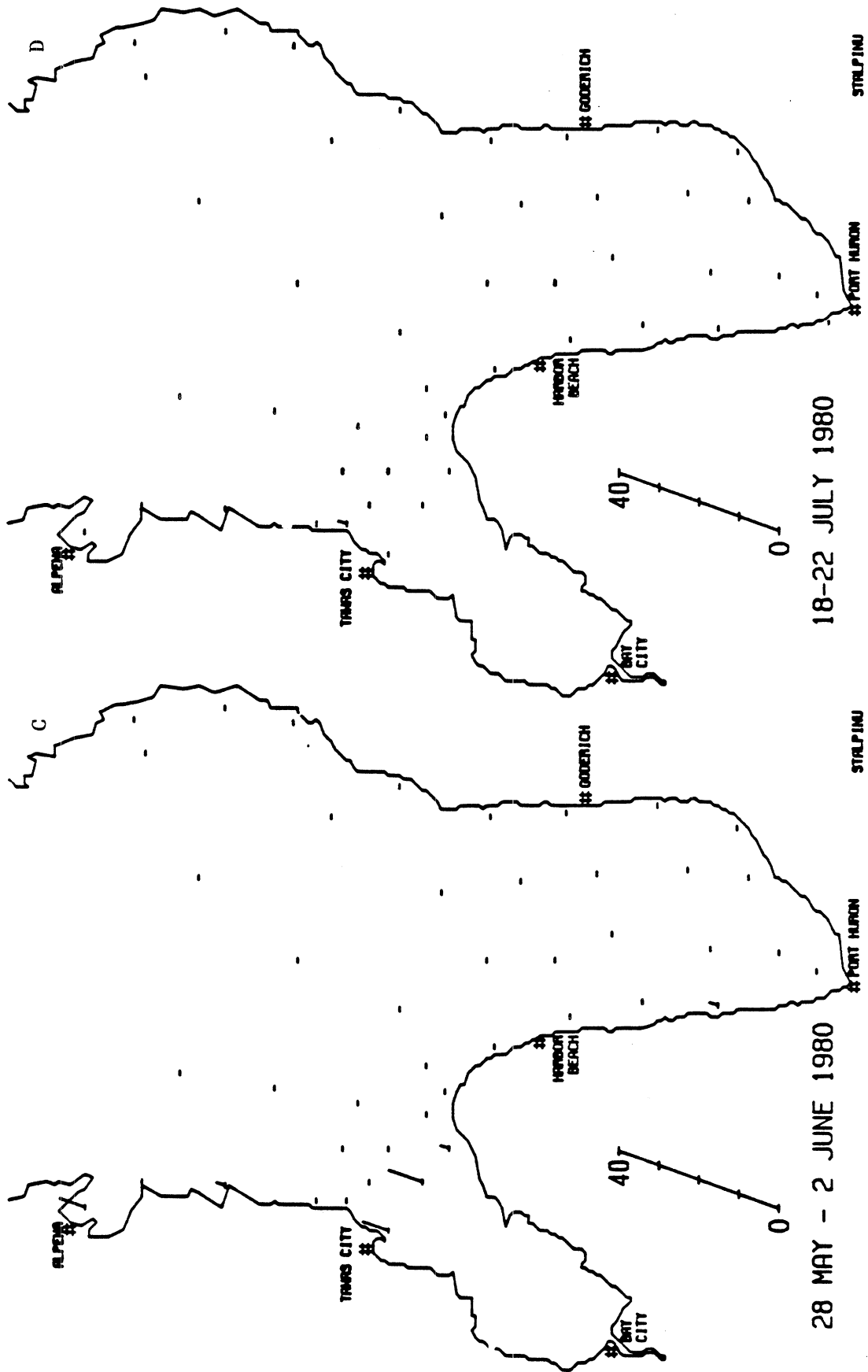


FIG. 28. (continued)

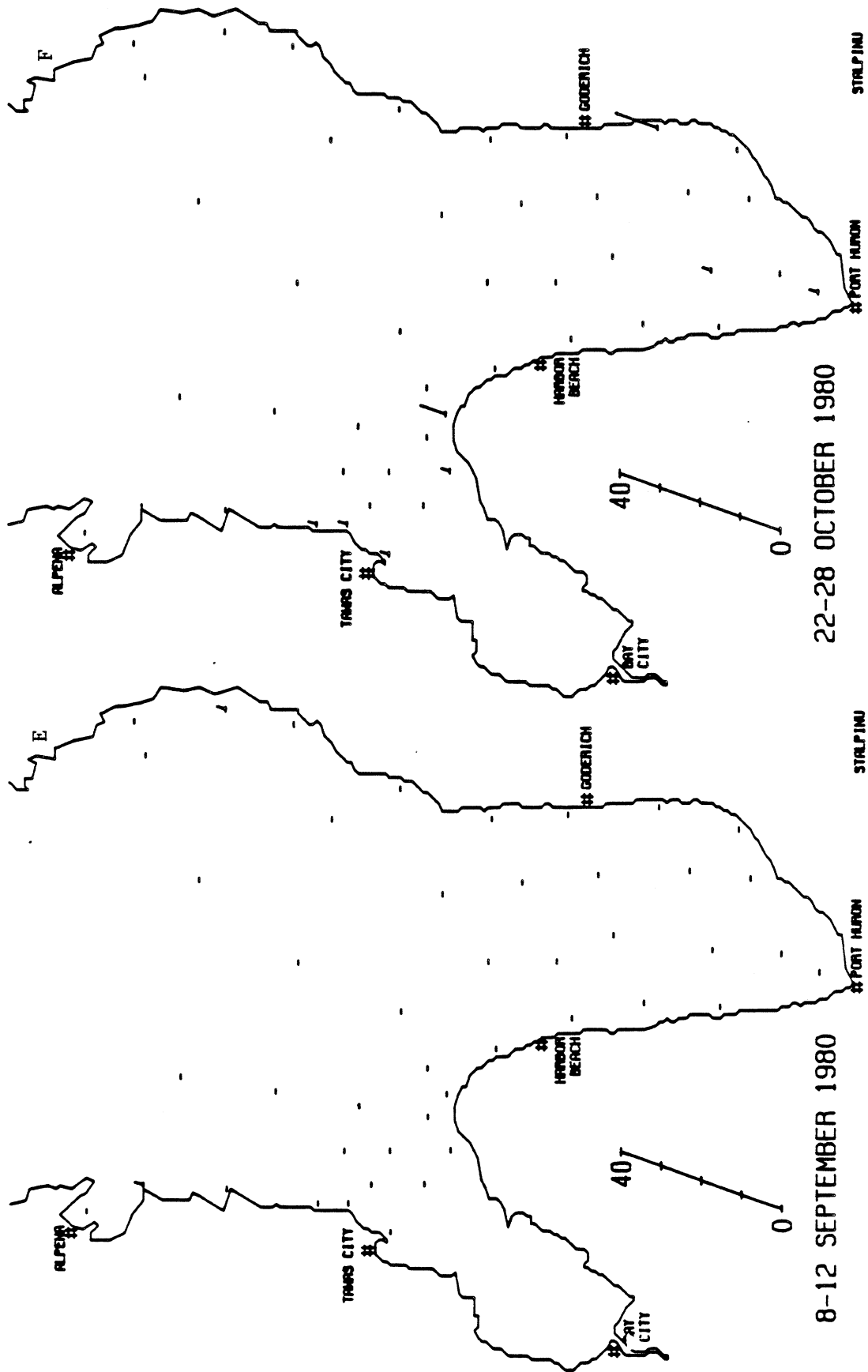


FIG. 28. (continued)

Stephanodiscus binderanus--

This species of Stephanodiscus is a colonial form which is associated with degraded water quality. In the 1950s it was considered a nuisance species since it clogged filters at water intake facilities (Vaughn 1961). During April (Fig. 29A), it exhibited low abundances in outer Saginaw Bay and on the southern U.S. shoreline. In May (Fig. 29B), it was observed in outer Saginaw Bay and associated waters, reaching its greatest abundance for the season. Similarly in June (Fig. 29C), it was only recorded in Saginaw Bay and the U.S. coastline south of the bay. A single occurrence was observed north of Tawas City during October (Fig. 29D).

Stephanodiscus hantzschii--

This species is a small centric form reported from the upper Great Lakes as a minor assemblage component. In April (Fig. 30A), this species exhibited its greatest average abundance for the sampling season. Highest cell numbers were seen in outer Saginaw Bay and in the lower U.S. nearshore zone. Moderate abundances were also observed offshore in the southern basin. An erratic distribution was recorded in May (Fig. 30B) with a single, large occurrence south of Goderich. During June (Fig. 30C), highest abundances were observed in the offshore central basin with distribution being centered in offshore zones. In September (Fig. 30D), low abundances were seen in the Canadian nearshore, whereas in October (Fig. 30E), most occurrences were reported from Saginaw Bay and adjacent waters.

Stephanodiscus minutus--

S. minutus is a commonly reported diatom from the Great Lakes. It may be also reported as S. astrea var. minutula. It attains its greatest cell numbers

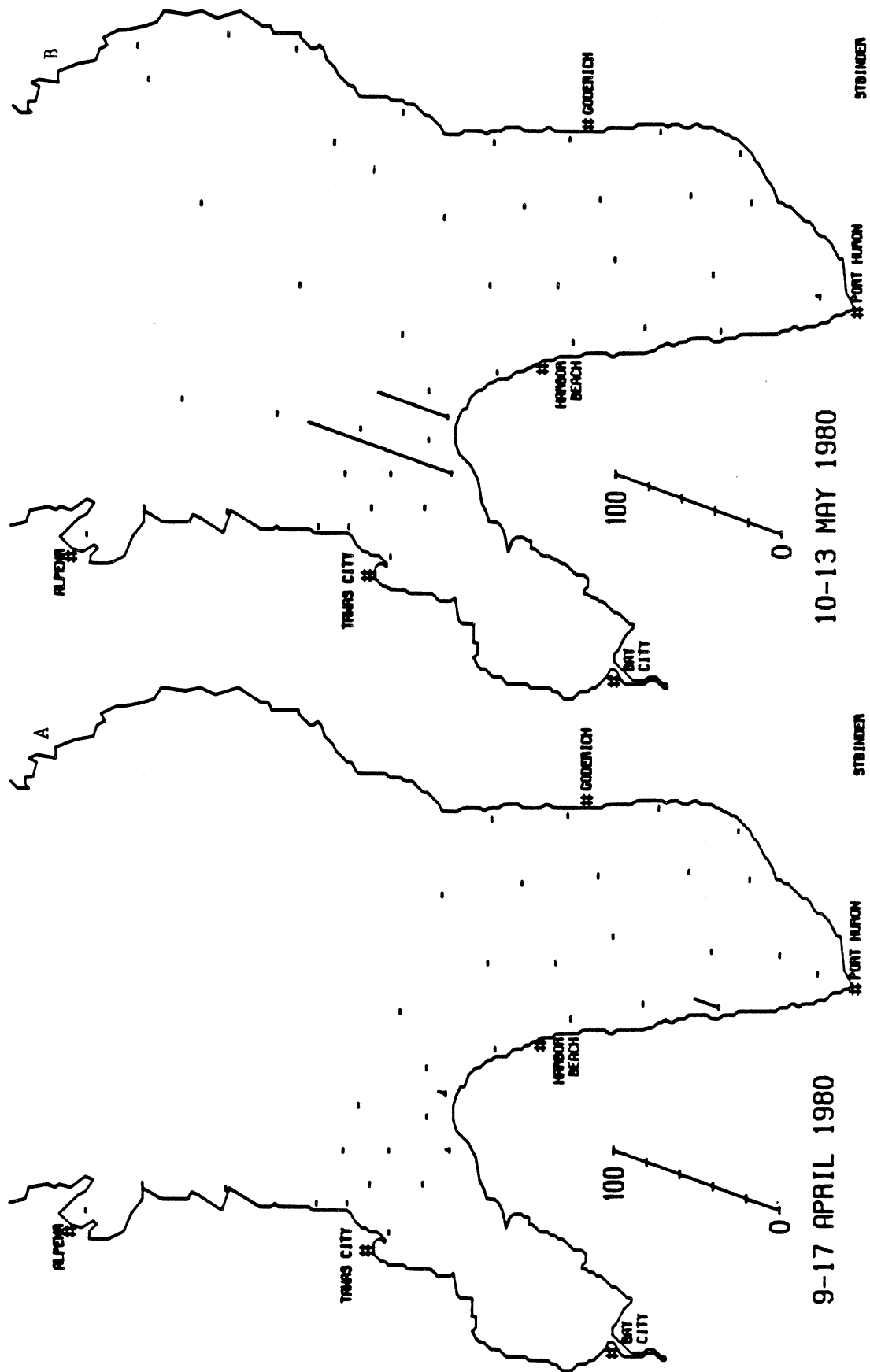


FIG. 29. Distribution of Stephanodiscus binderanus.

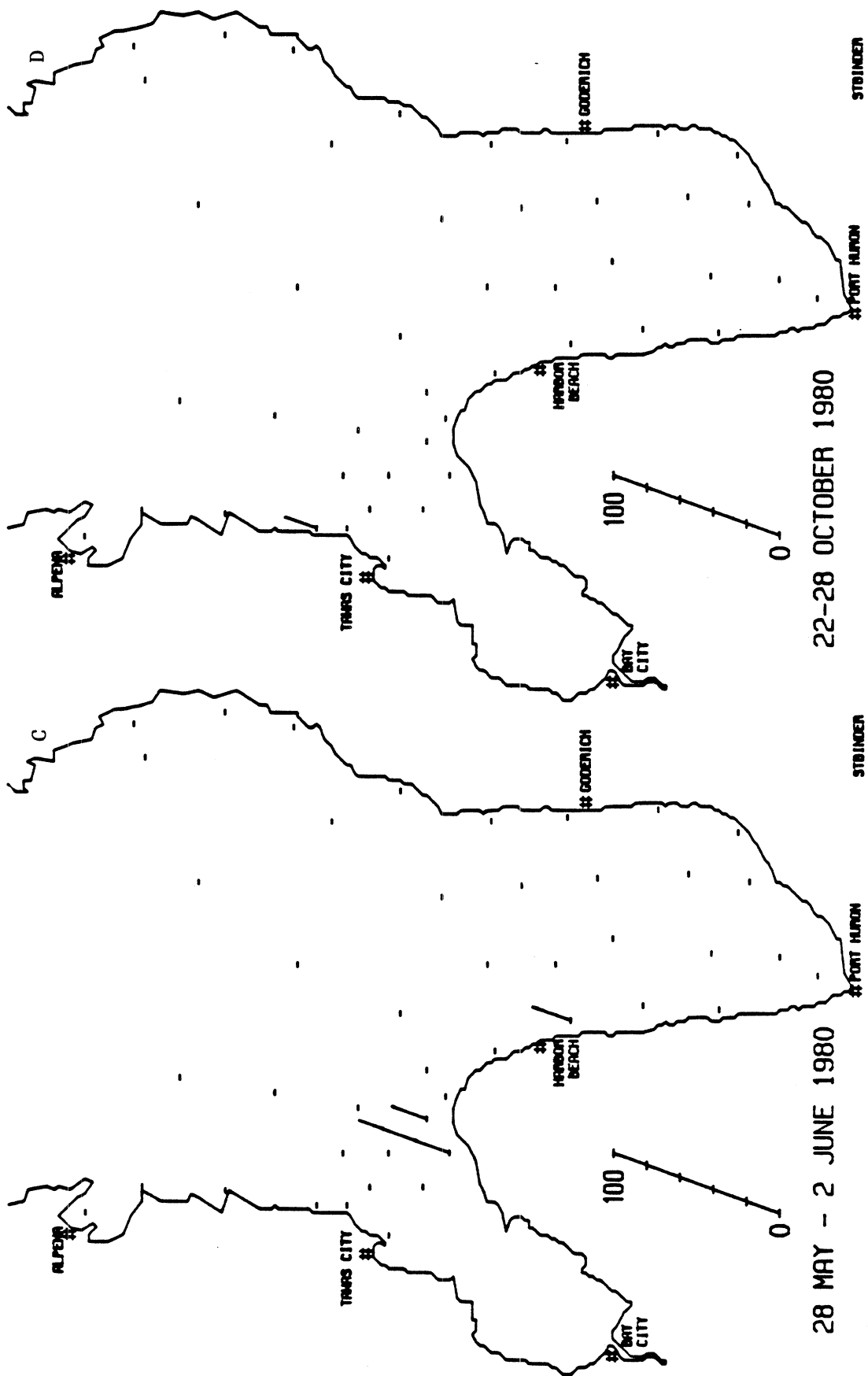


FIG. 29. (continued)

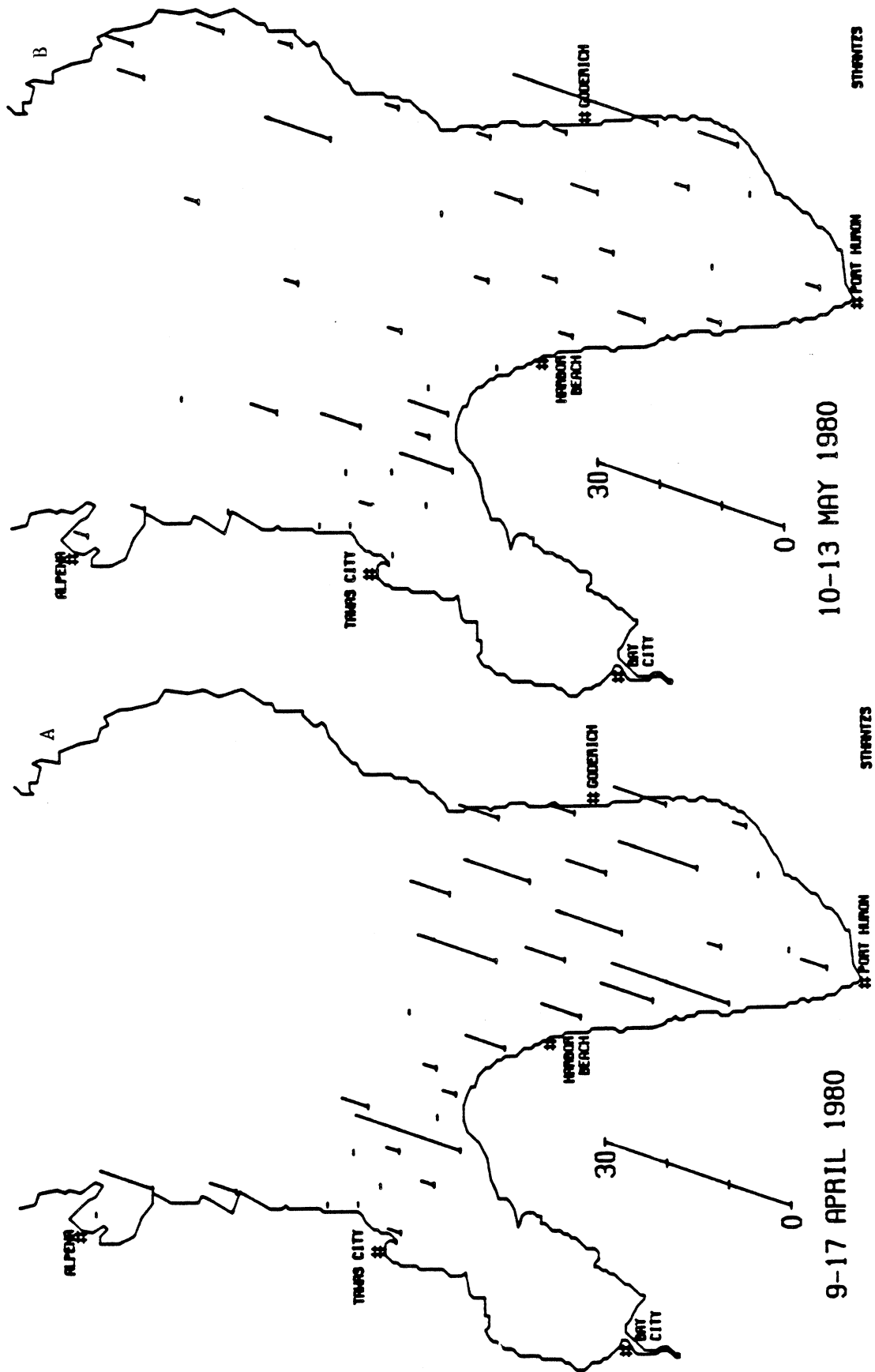


FIG. 30. Distribution of *Stephanodiscus hantzschii*.

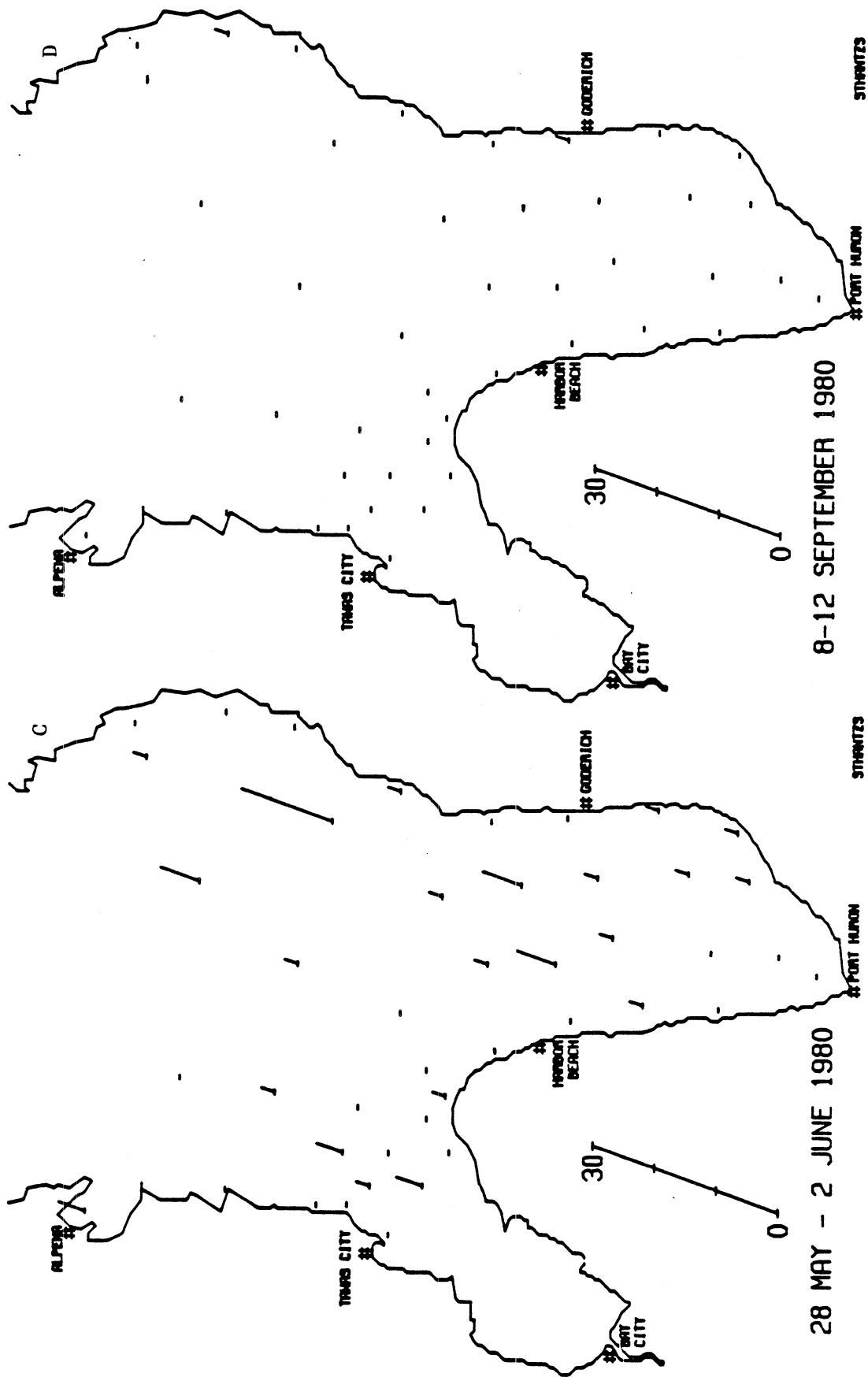


FIG. 30. (continued)

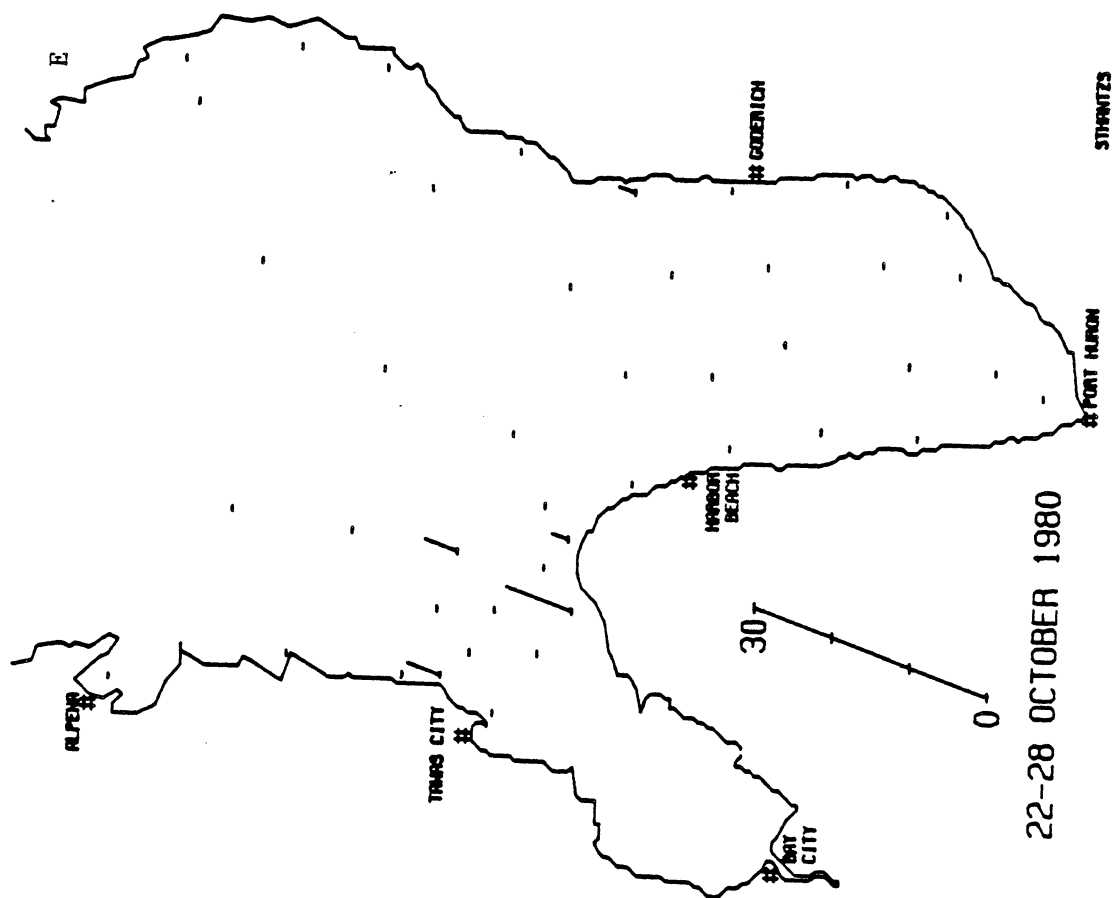


FIG. 30. (continued)

in the spring and is a common component of disturbed habitats. It was more or less uniformly distributed in April (Fig. 31A), with slightly elevated abundances in the offshore waters of the southern basin. In May (Fig. 31B), it exhibited reduced abundances with peaks south of Goderich and larger cell numbers in the central basin compared to the southern. During June (Fig. 31C), high abundances were observed in the offshore central basin with decreasing abundances toward the upper southern basin. During July (Fig. 31D), a few sporadic occurrences were observed on the northern U.S. coastal zone. Conversely, in September (Fig. 31E), very low abundances were observed in the central basin nearshore zone and the lowermost portion of the southern basin. In October (Fig. 31F), slightly higher abundances were observed primarily in the central basin.

#### Stephanodiscus subtilis--

S. subtilis is reported from enriched harbors and rivermouth areas from the Great Lakes. This taxon may be synonymous with S. invisitatus Hohn and Hellerman (Hohn and Hellerman 1963). In all months sampled (Figs. 32A-32D) this species was observed in the Canadian nearshore zone south of Goderich. It reached its greatest abundance in June.

#### Synedra filiformis--

This species may be present in the spring or fall months, sometimes showing responses to nutrient enrichment. In April (Fig. 33A), it reached its highest abundance of the cruise season. Greatest standing crops were observed in the nearshore zone of Saginaw Bay and south of the bay. During May (Fig. 33B), this species was widely distributed throughout the study area. It was most abundant in the nearshore zone around the entire lake perimeter but

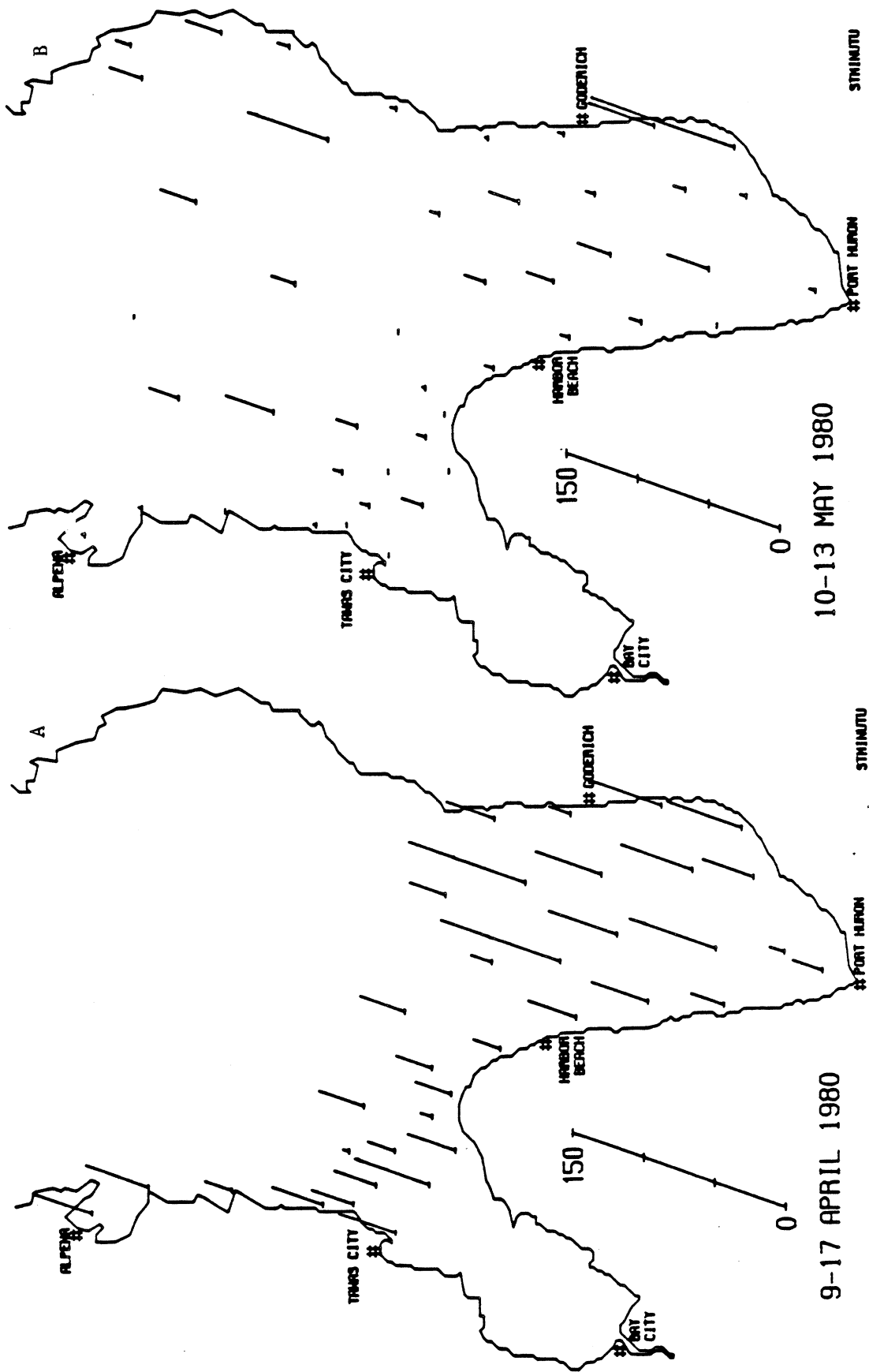


FIG. 31. Distribution of *Stephanodiscus minutus*.

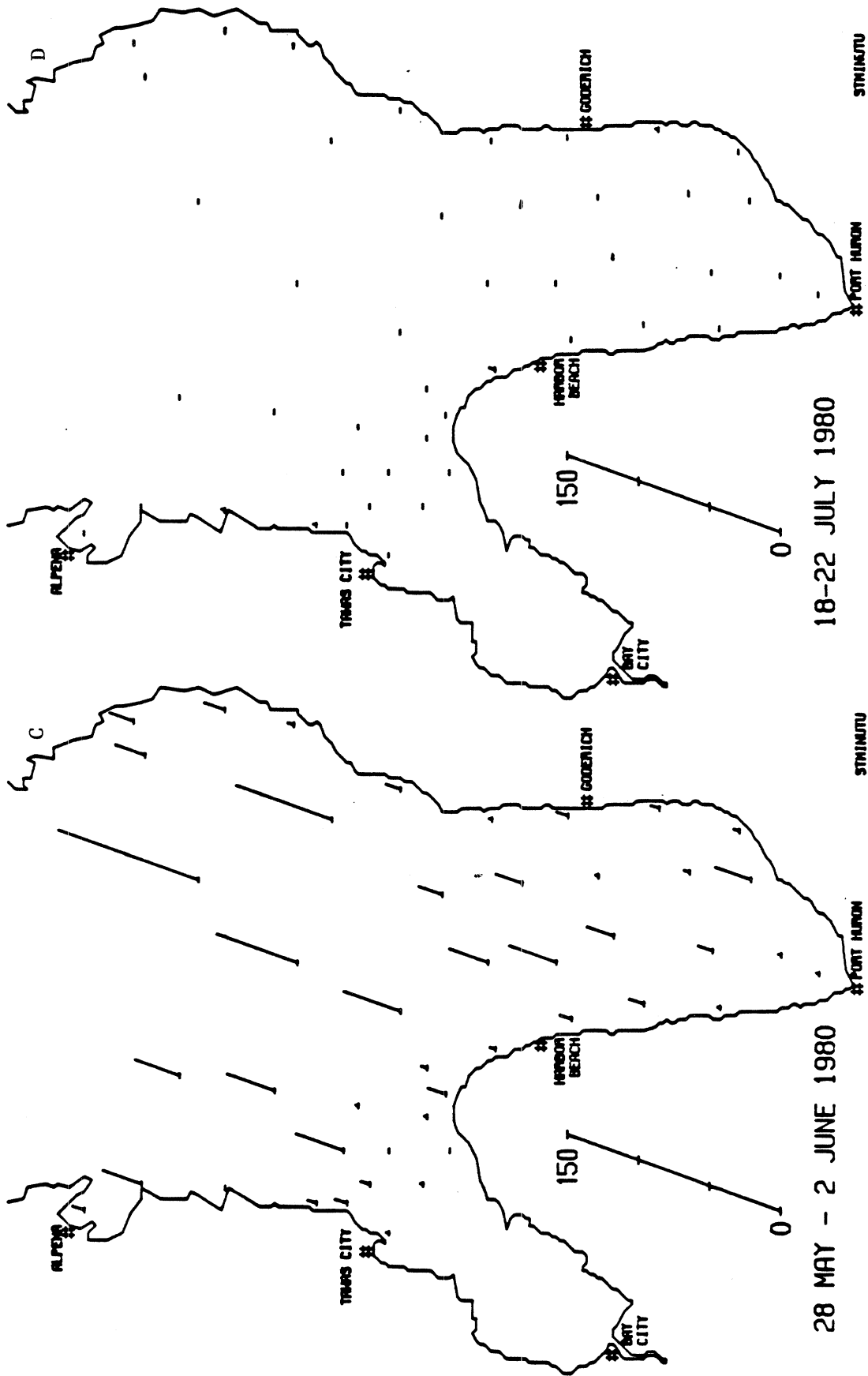


FIG. 31. (continued)

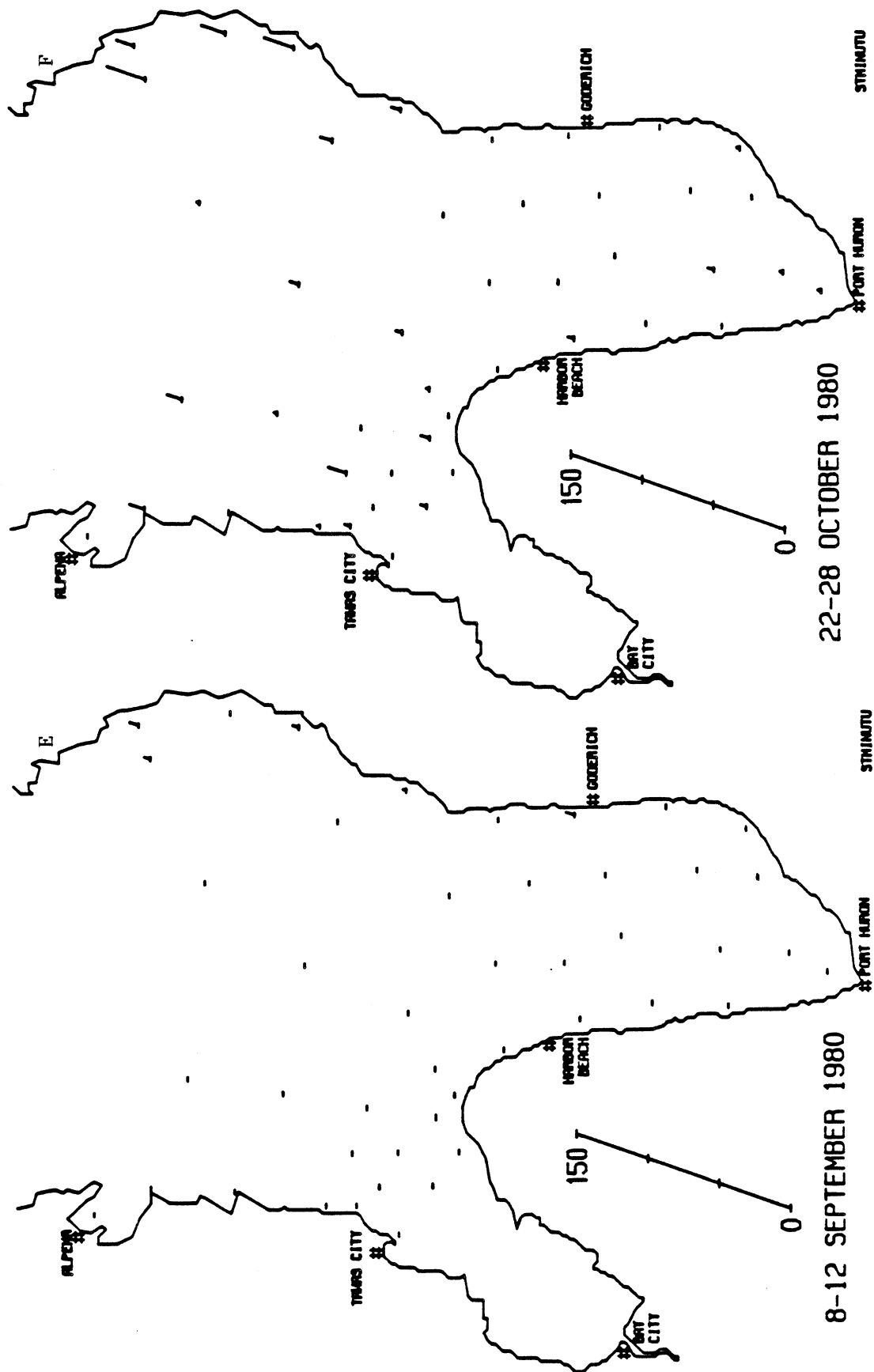


FIG. 31. (continued)

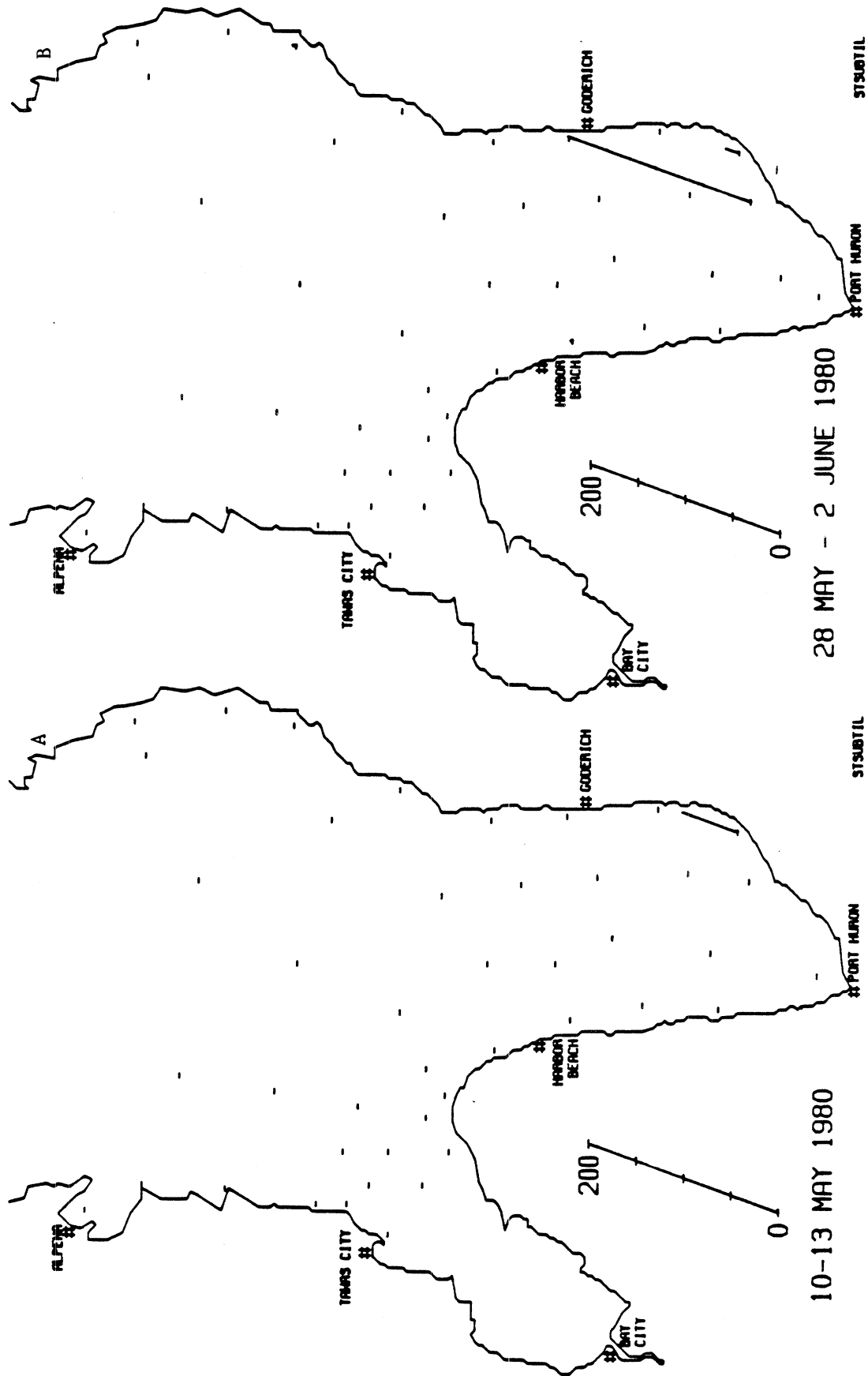


FIG. 32. Distribution of Stephanodiscus subtilis.

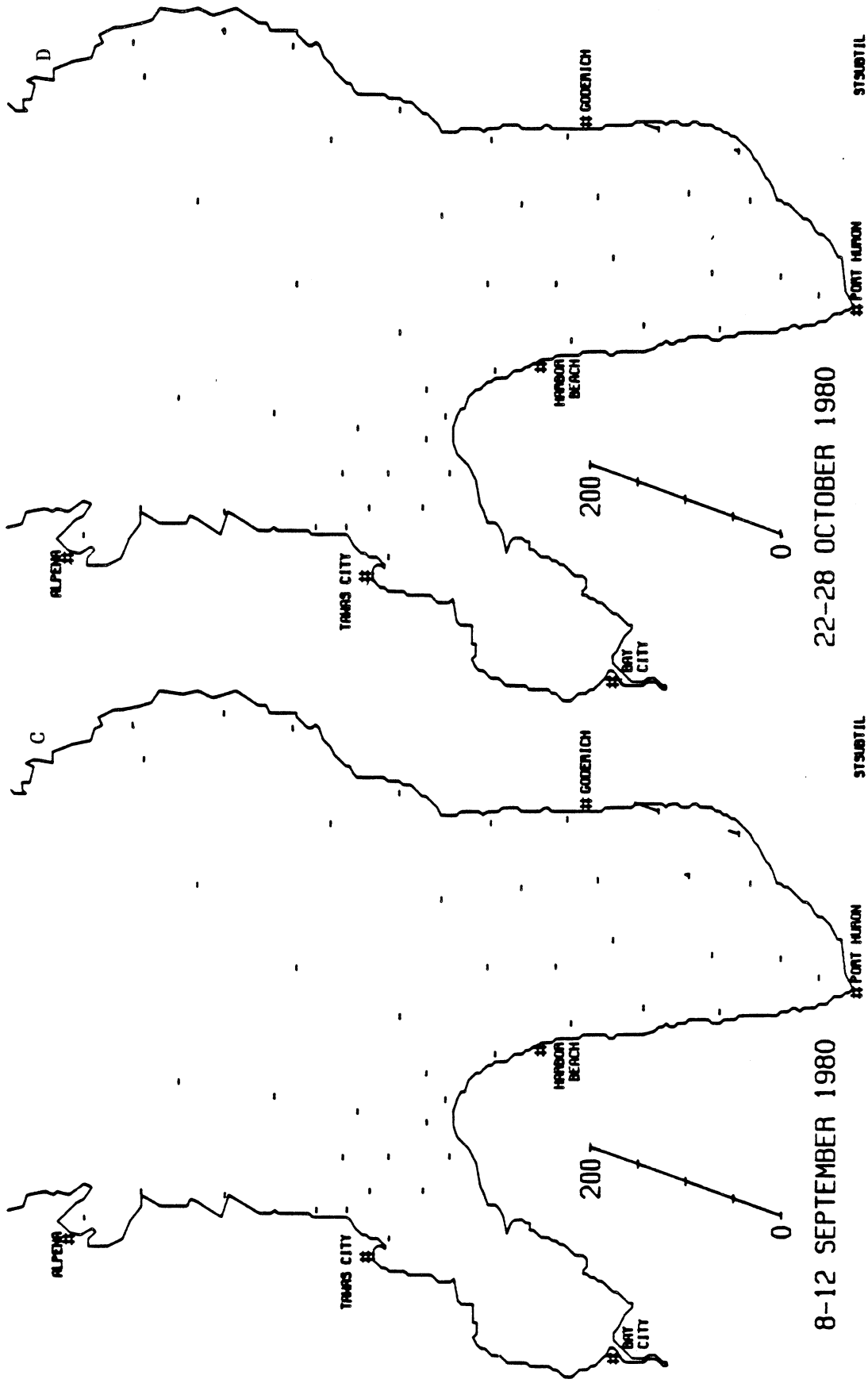


FIG. 32. (continued)

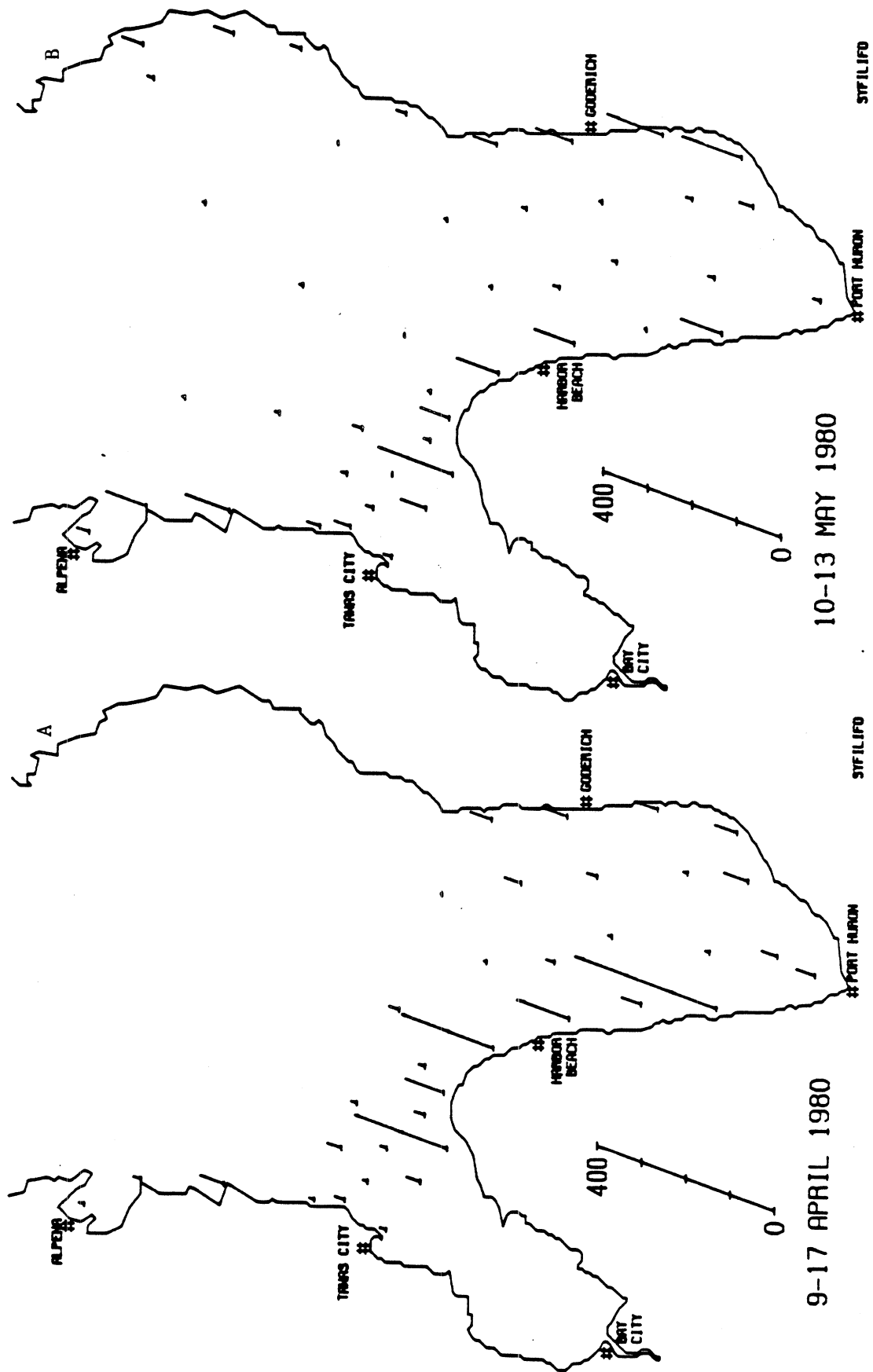


FIG. 33. Distribution of *Synedra filiformis*.

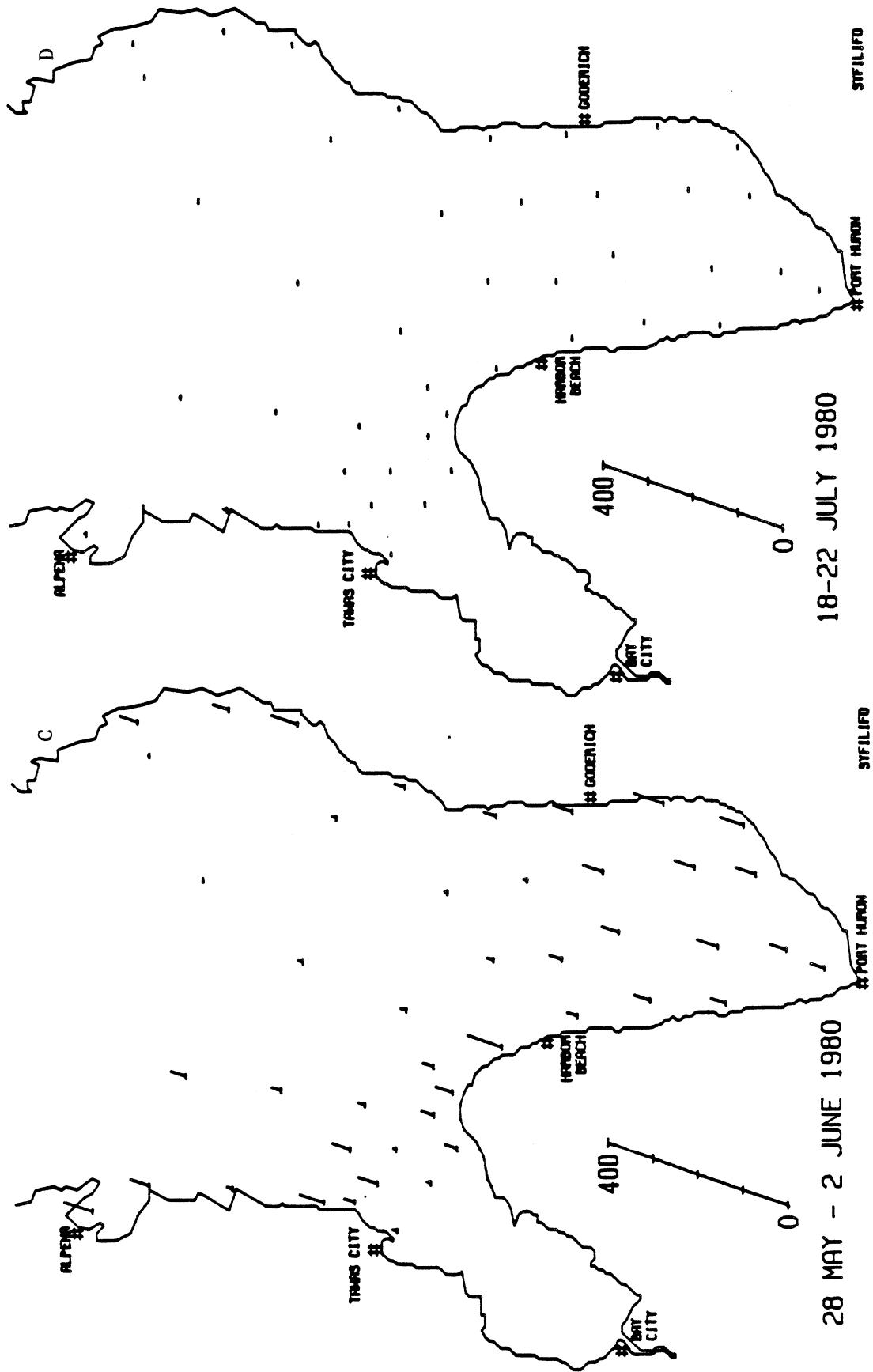


FIG. 33. (continued)

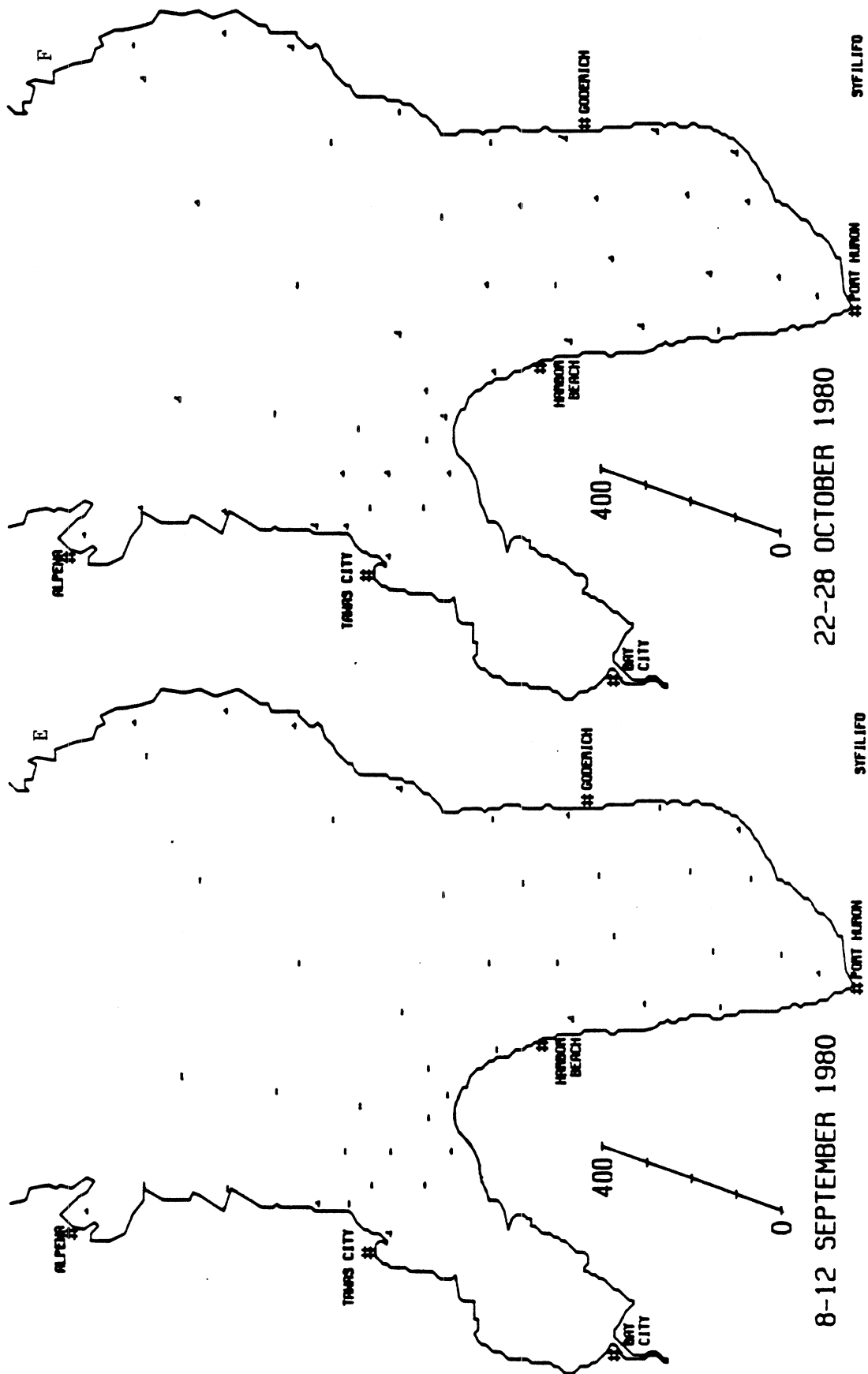


FIG. 33. (continued)

at comparatively lower abundances to the preceding month. During June (Fig. 33C), slightly lower abundances were recorded showing a uniform distribution. During July and September (Figs. 33D and 33E), few occurrences were observed. In October (Fig. 33F), slightly increased values were observed over the study area with a wider distribution.

Synedra ostenfeldii--

This species usually exhibits greatest abundance and occurrence during the spring months, as was observed in this study. In April (Fig. 34A), it showed highest concentrations in the nearshore zone on the U.S. coastline. During May (Fig. 34B) it again reached greatest abundance in coastal zones around the study area but was observed in the offshore waters of both basins. In June (Fig. 34C), it attained its greatest cell concentrations for the season. It was widespread throughout the study area with most peaks in the central basin. Cell numbers were greatly reduced in July (Fig. 34D) and populations were restricted to the central basin. It was recorded at very low abundances with a sporadic distribution in October (Fig. 34E).

Tabellaria fenestrata--

This chain-forming species is commonly observed in the net plankton from all of the Great Lakes. In April (Fig. 35A), it was uniformly distributed over the southern basin with slightly elevated cell densities in the nearshore zone of the U.S. coastline. In May (Fig. 35B), highest abundances were seen near Thunder Bay but it was widespread in the study area. This species was again found throughout the study area in June (Fig. 35C), with peaks in the nearshore zone south of Goderich. Greatly reduced occurrences and abundances were observed for July (Fig. 35D), with occurrences primarily in the nearshore

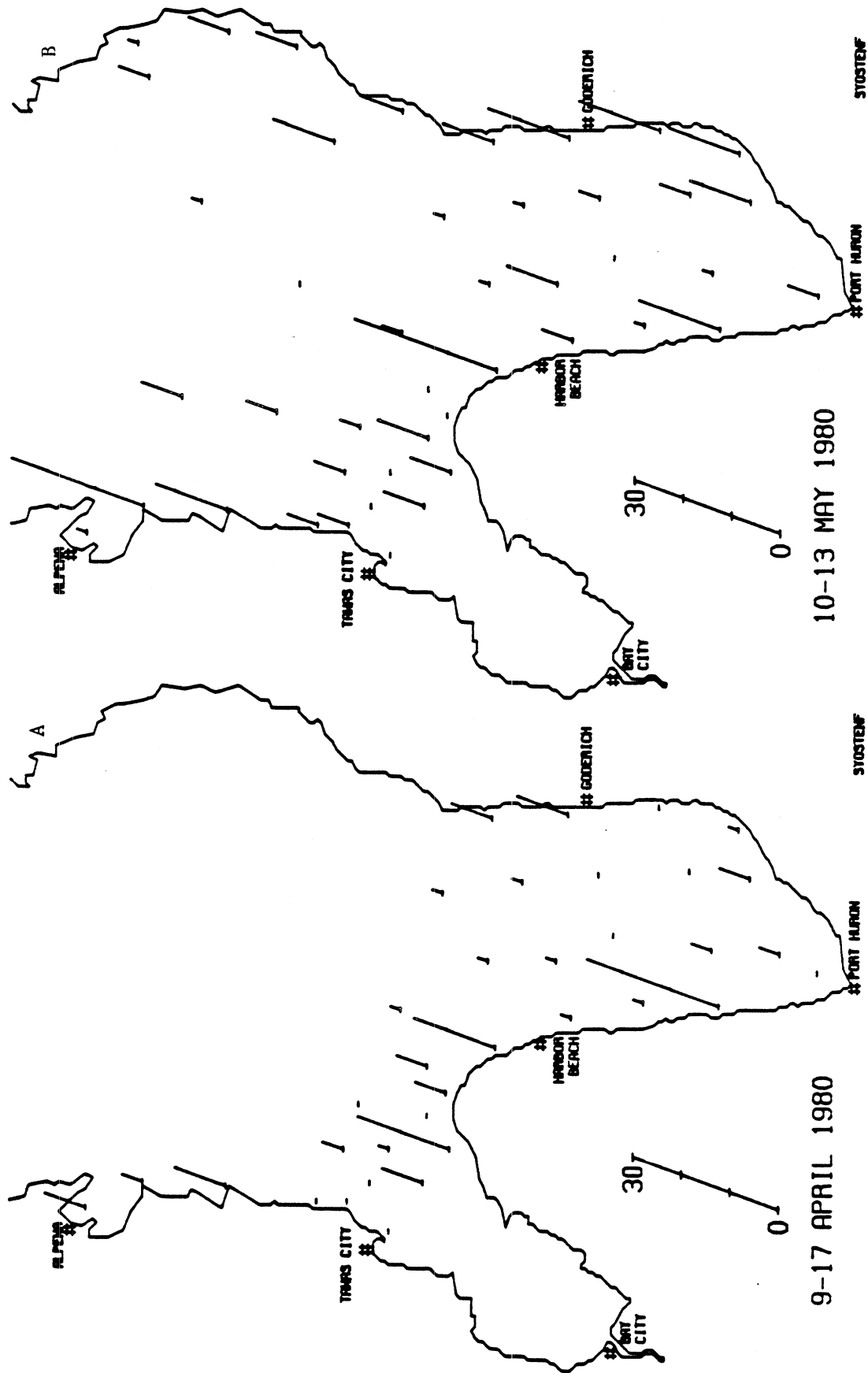


FIG. 34. Distribution of *Synedra ostenfeldii*.

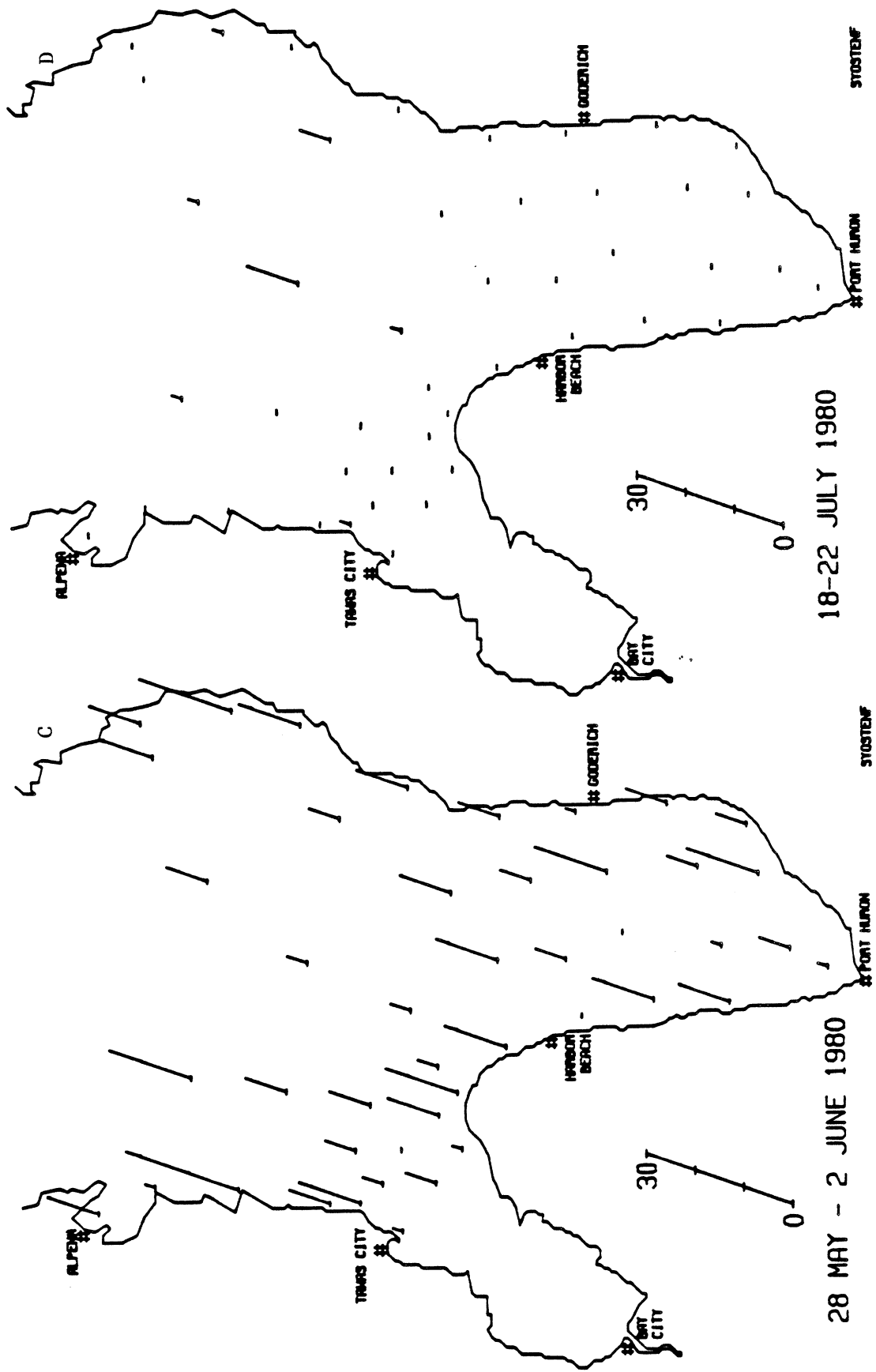


FIG. 34. (continued)

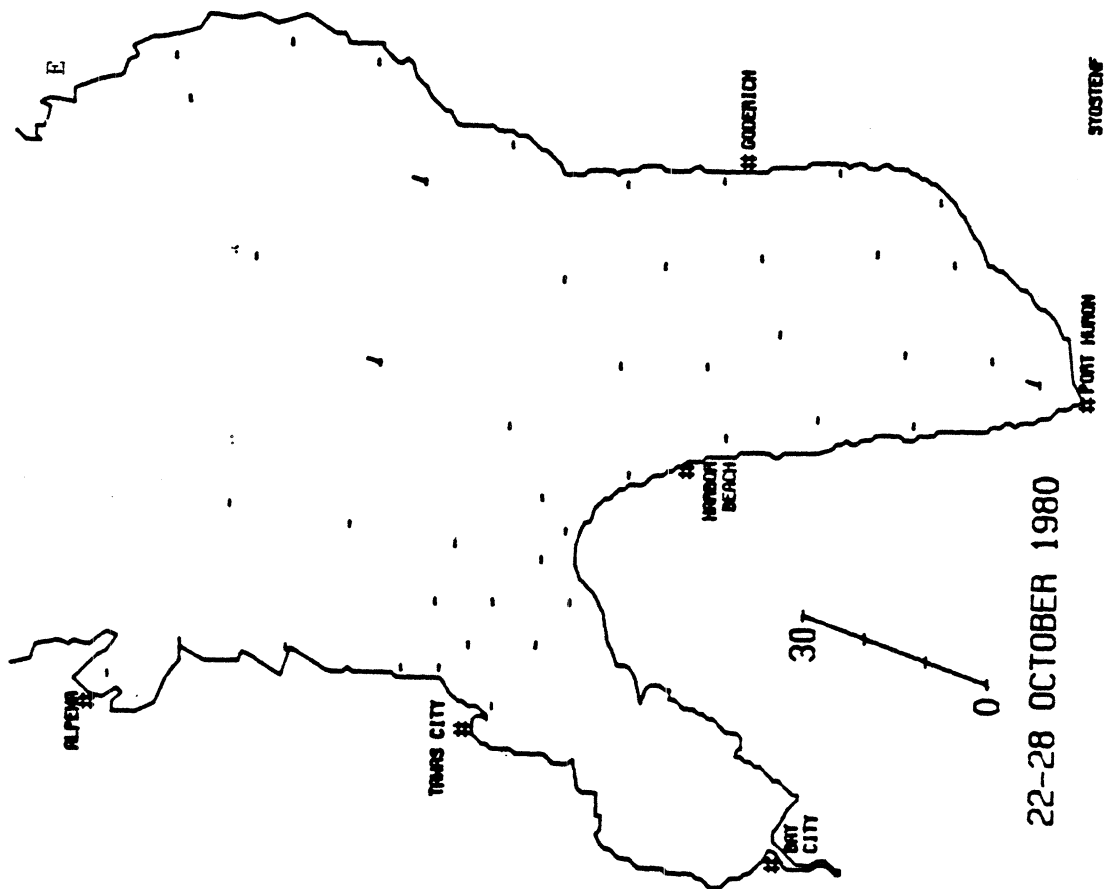


FIG. 34. (continued)

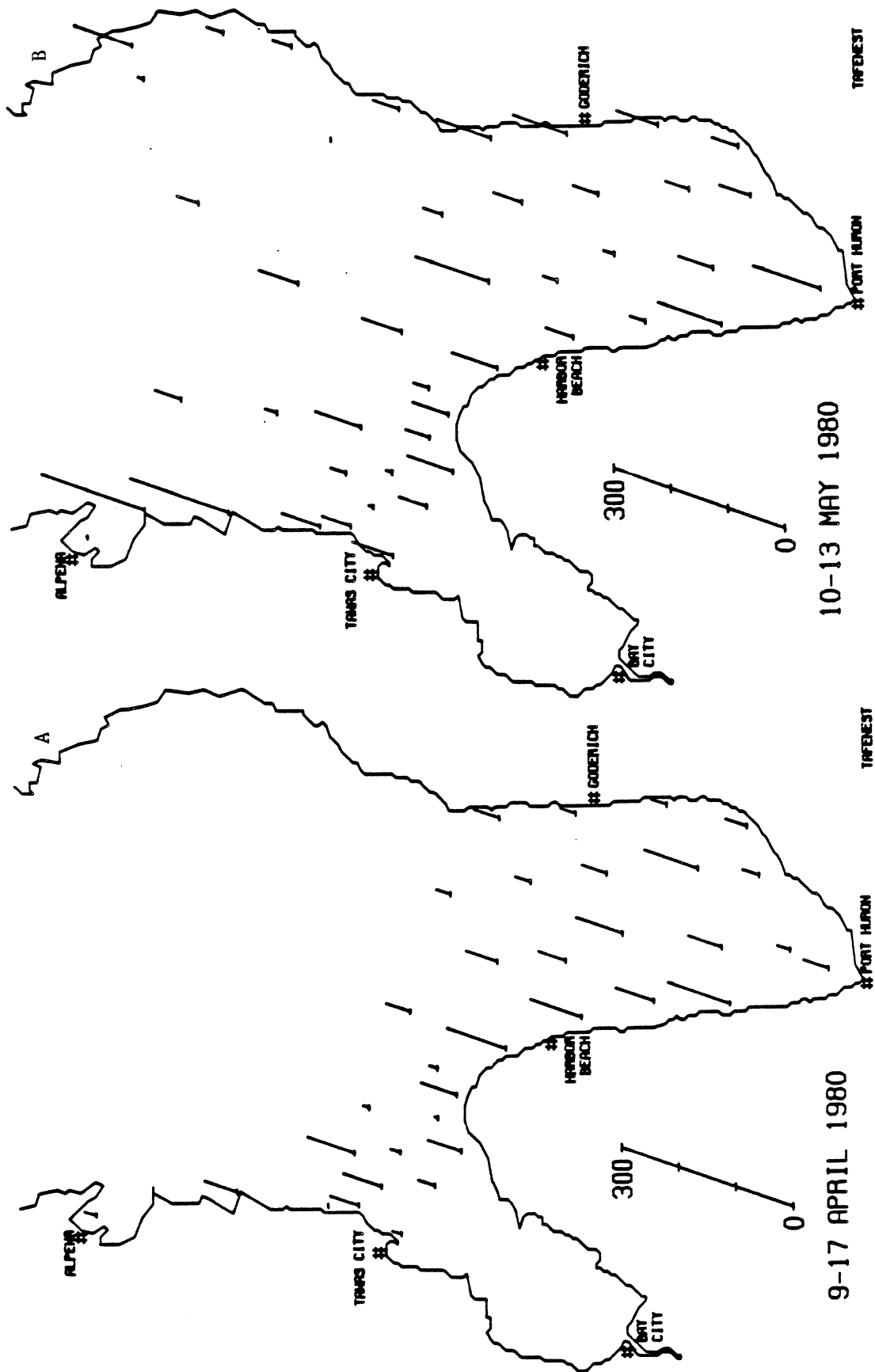


FIG. 35. Distribution of *Tabellaria fenestrata*.

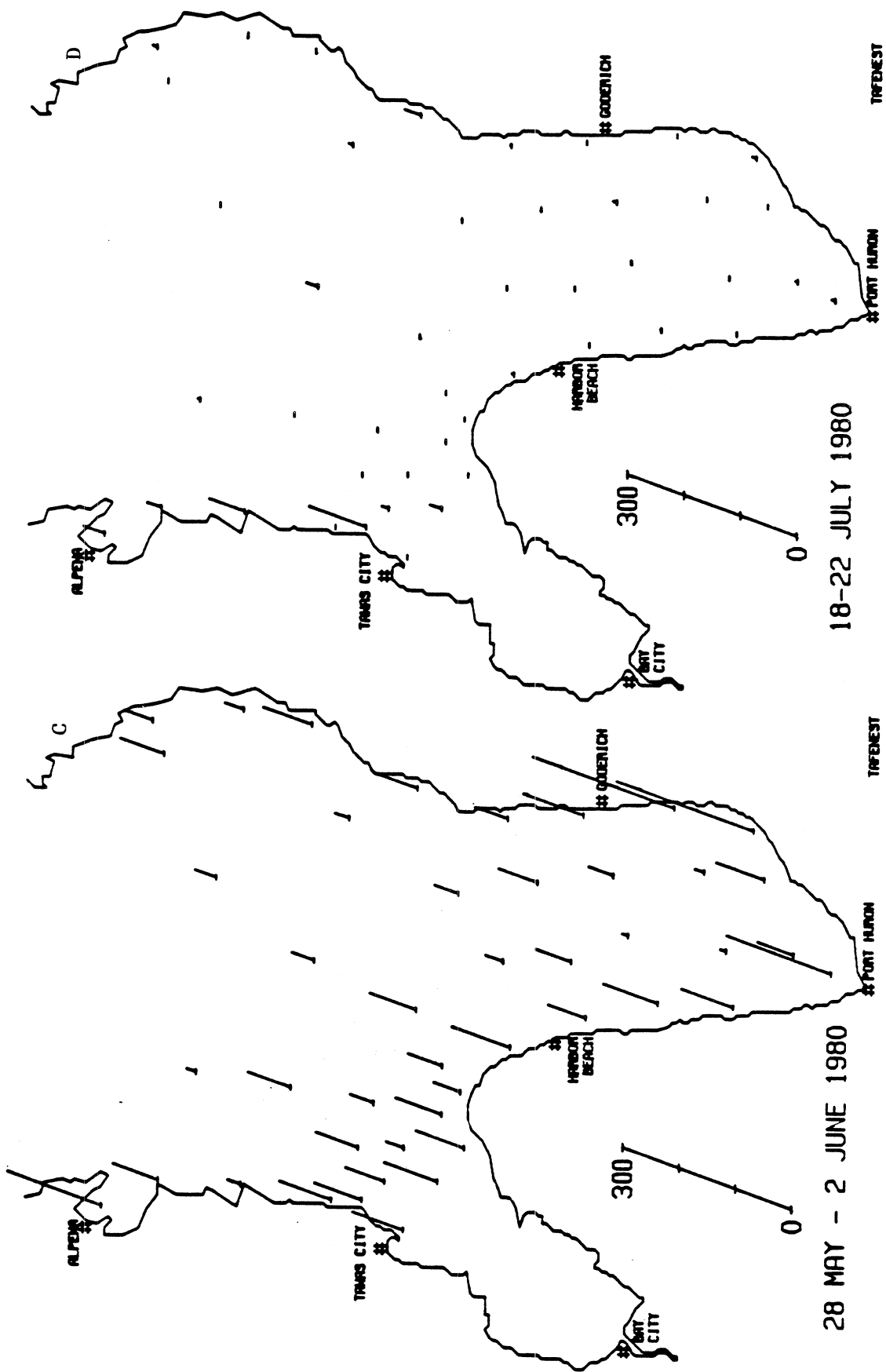


FIG. 35. (continued)

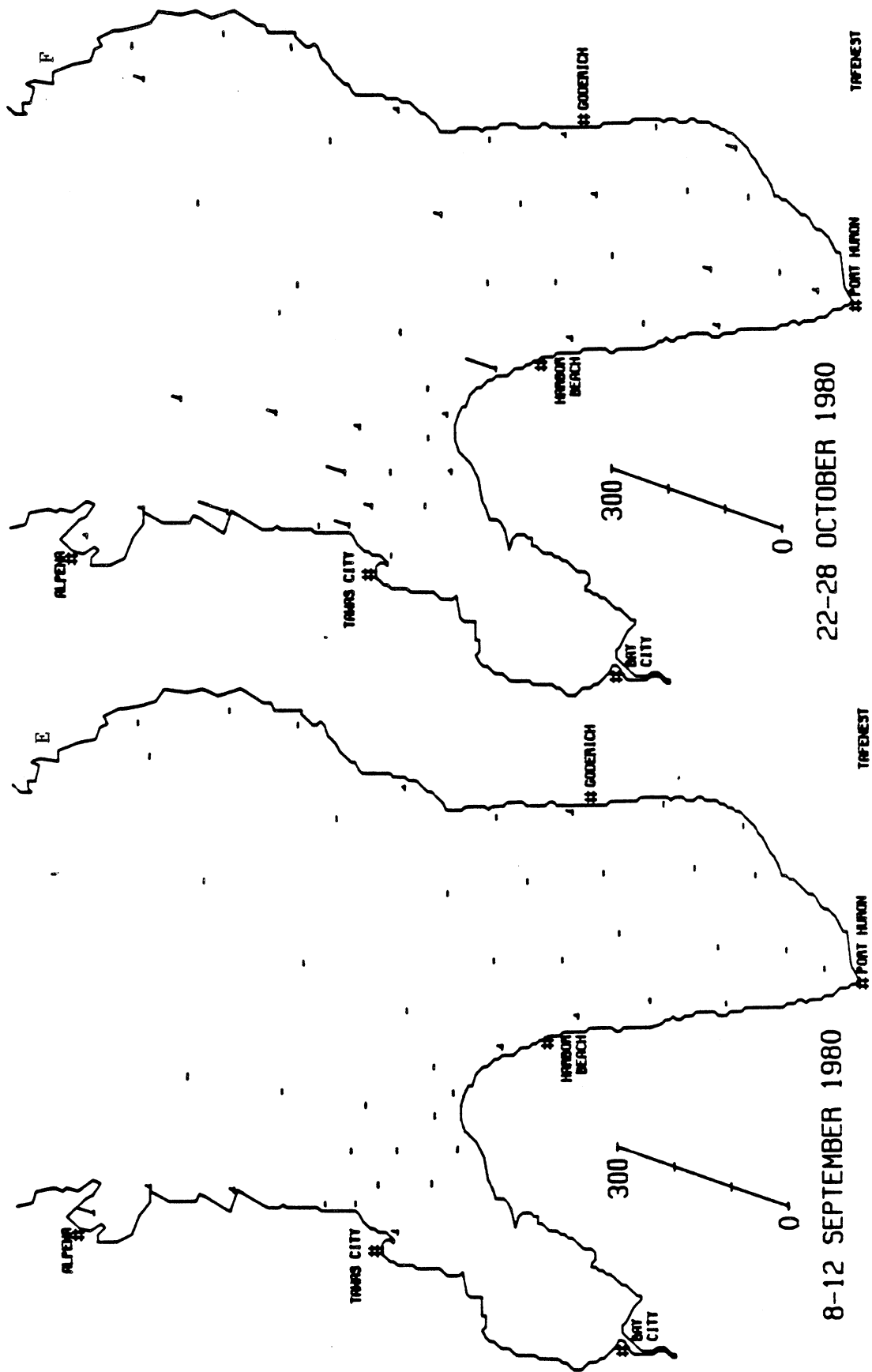


FIG. 35. (continued)

zone between Alpena and Tawas City. Extremely low cell densities were seen in September (Fig. 35E), with slightly increased abundances during October (Fig. 35F).

#### Chlorophyta - Green Algae

Green algae are most commonly observed in productive ponds and shallow lakes (Hutchinson 1967) during the summer months. In the Great Lakes, they are recorded in highest abundances during the summer in enriched areas, e.g., the western basin of Lake Erie (Munawar and Munawar 1976). However, some genera are noted during other seasons in offshore waters. In southern Lake Huron, members of this group exhibited extremely erratic distributions. In April (Fig. 36A), abundances were fairly low, with greatest cell numbers observed north of Tawas City and in the mid-southern basin. During May (Fig. 36B), highest standing crops were observed in nearshore zones, particularly in the southern basin. A large peak was also observed on the Canadian shoreline in the northern portion of the central basin. Moderate abundances were seen in outer Saginaw Bay and in the lower central basin. Highest standing crops for June (Fig. 36C) were in the southern basin. Several moderate abundances were observed in outer Saginaw Bay and northward from the bay. In July (Fig. 36D), highest cell densities were seen in outer Saginaw Bay and its associated waters. Some moderate abundances were observed near Alpena and southward. Distinctly lower abundance was recorded through the remainder of the study area. During September (Fig. 36E), very large cell densities were recorded at one station in the offshore waters on the west side of the central basin. Moderate abundances were observed over the study area, with slightly elevated abundances in the waters adjacent to Saginaw Bay.

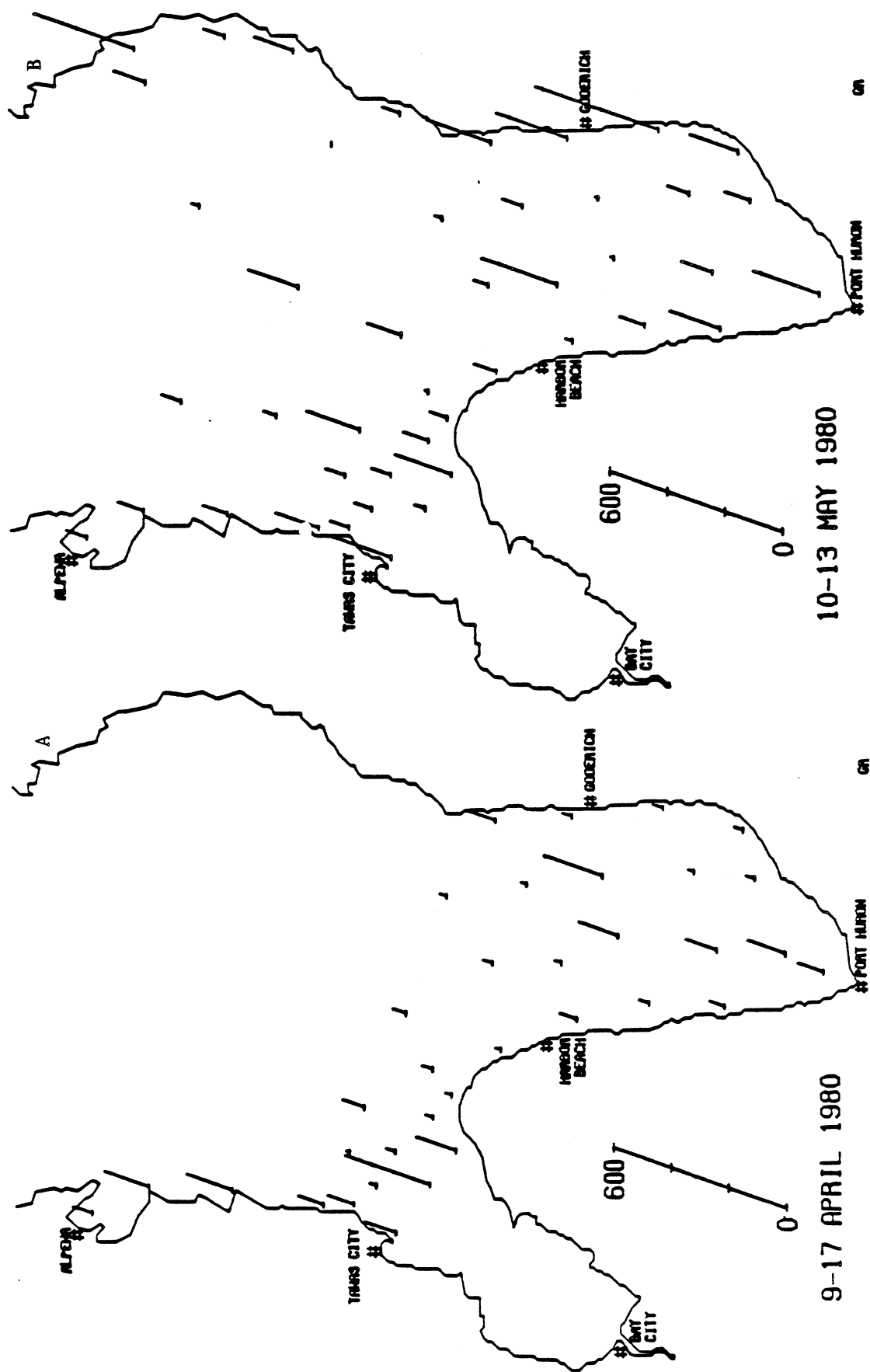


FIG. 36. Seasonal distribution and abundance trends (cells/mL) of green algae, 1980.

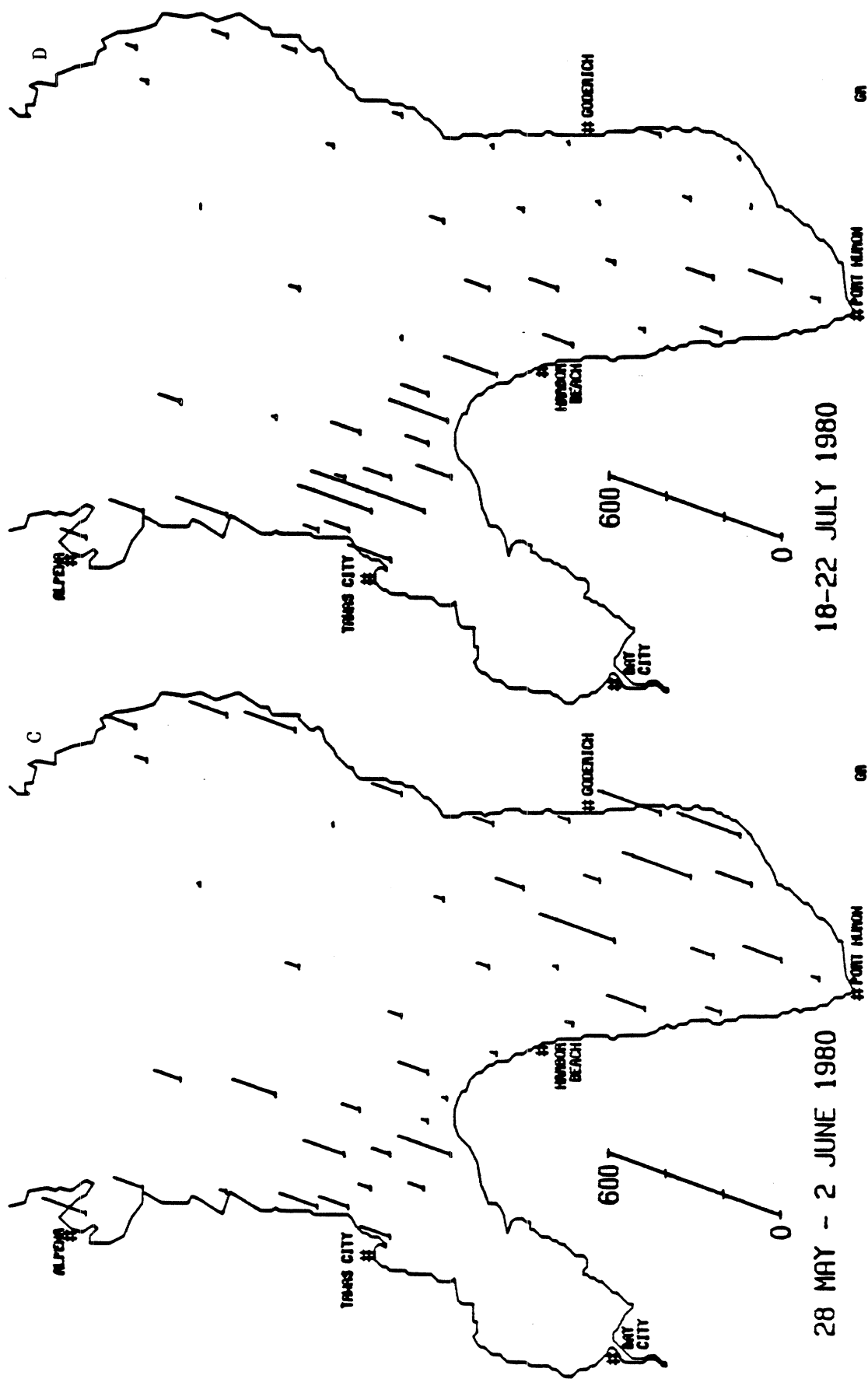


FIG. 36. (continued)

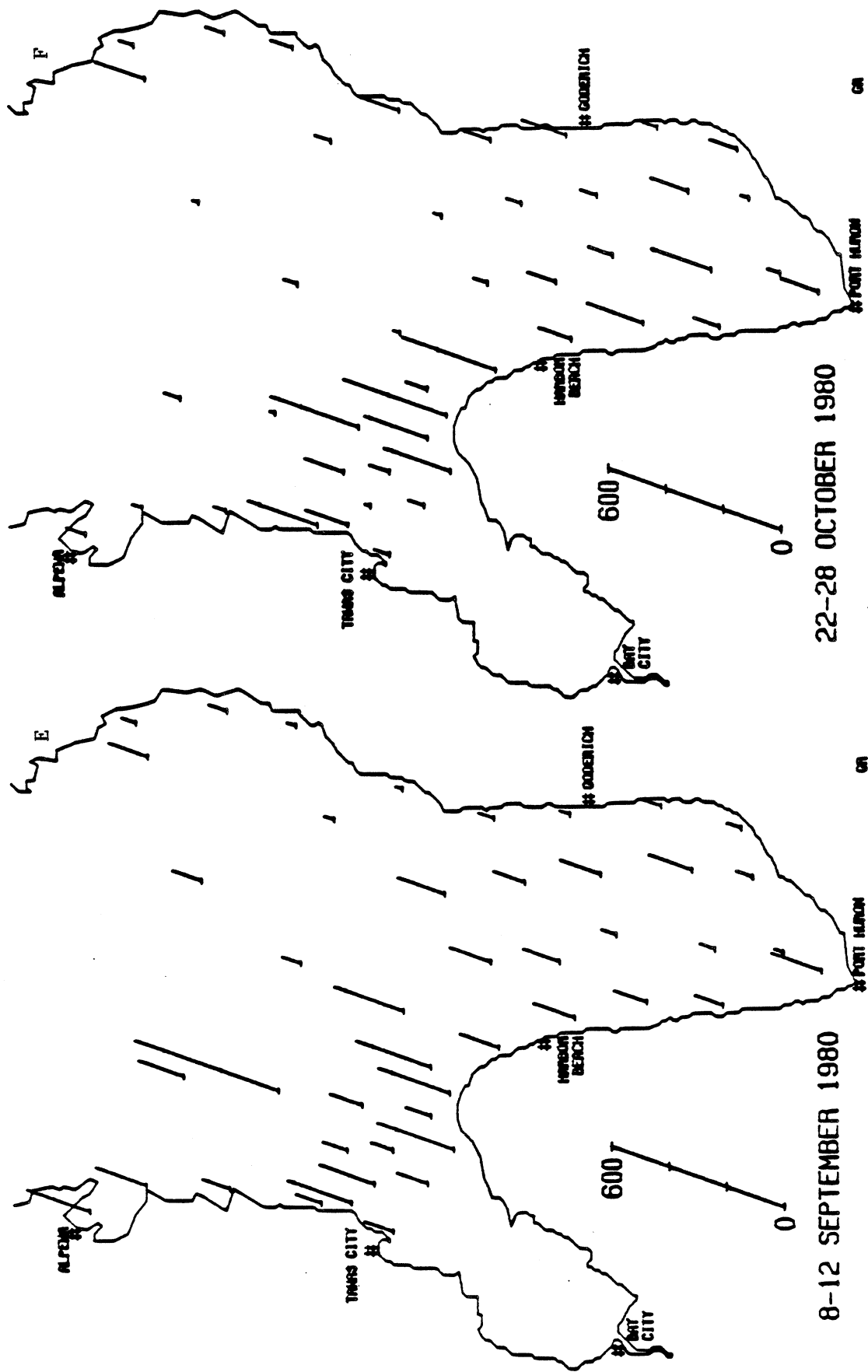


FIG. 36. (continued)

Comparatively low cell numbers were noted along the entire Canadian coastline. Greatest abundances of green algae were observed in the area adjacent to Saginaw Bay in October (Fig. 36F). Higher standing crops were observed in the southern basin compared to the central basin.

Ankistrodesmus sp. #3--

This green alga is not satisfactorily placed at the species level. It has morphological characteristics similar to Ankistrodesmus falcatus and may be an undescribed form of the species. Uniformly low abundances were seen in April (Fig. 37A), with slightly elevated cell numbers in nearshore zones and outer Saginaw Bay. In May (Fig. 37B), cell densities slightly increased, still with the highest abundances in coastal areas. Highest abundances in June (Fig. 37C) were recorded in outer Saginaw Bay and the interface zone. Low abundances were observed in offshore waters excepting a north-south transect of stations in the mid-southern basin. In July (Fig. 37D), a very large peak was observed in the littoral zone between Alpena and Tawas City. High values were also observed in the Saginaw Bay associated waters, and in general, abundances were largest on the western portion of the study area. During September and October (Figs. 37F and 37E), abundances were markedly reduced and revealed no apparent distributional trends.

Gloeocystis planctonica--

G. planctonica is commonly reported from the Great Lakes and inland lakes of the Great Lakes states (Prescott 1962). It appears to reach its greatest abundance in enriched areas of the Great Lakes. During April (Fig. 38A), standing crop was very low, showing no distributional patterns. Abundance in May (Fig. 38B) was slightly elevated from the previous month, with greatest

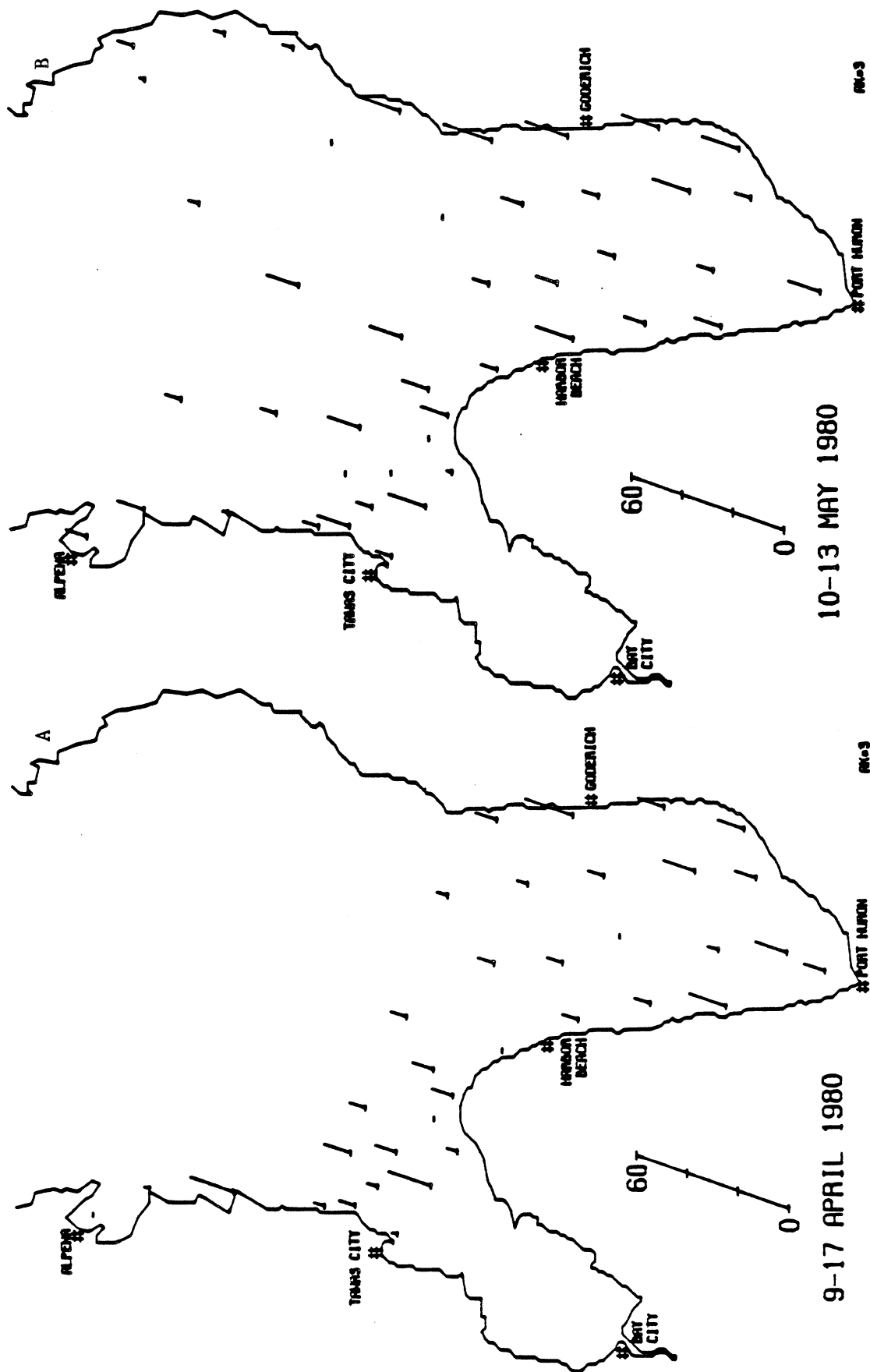


FIG. 37. Distribution of *Ankistrodesmus* sp. #3.

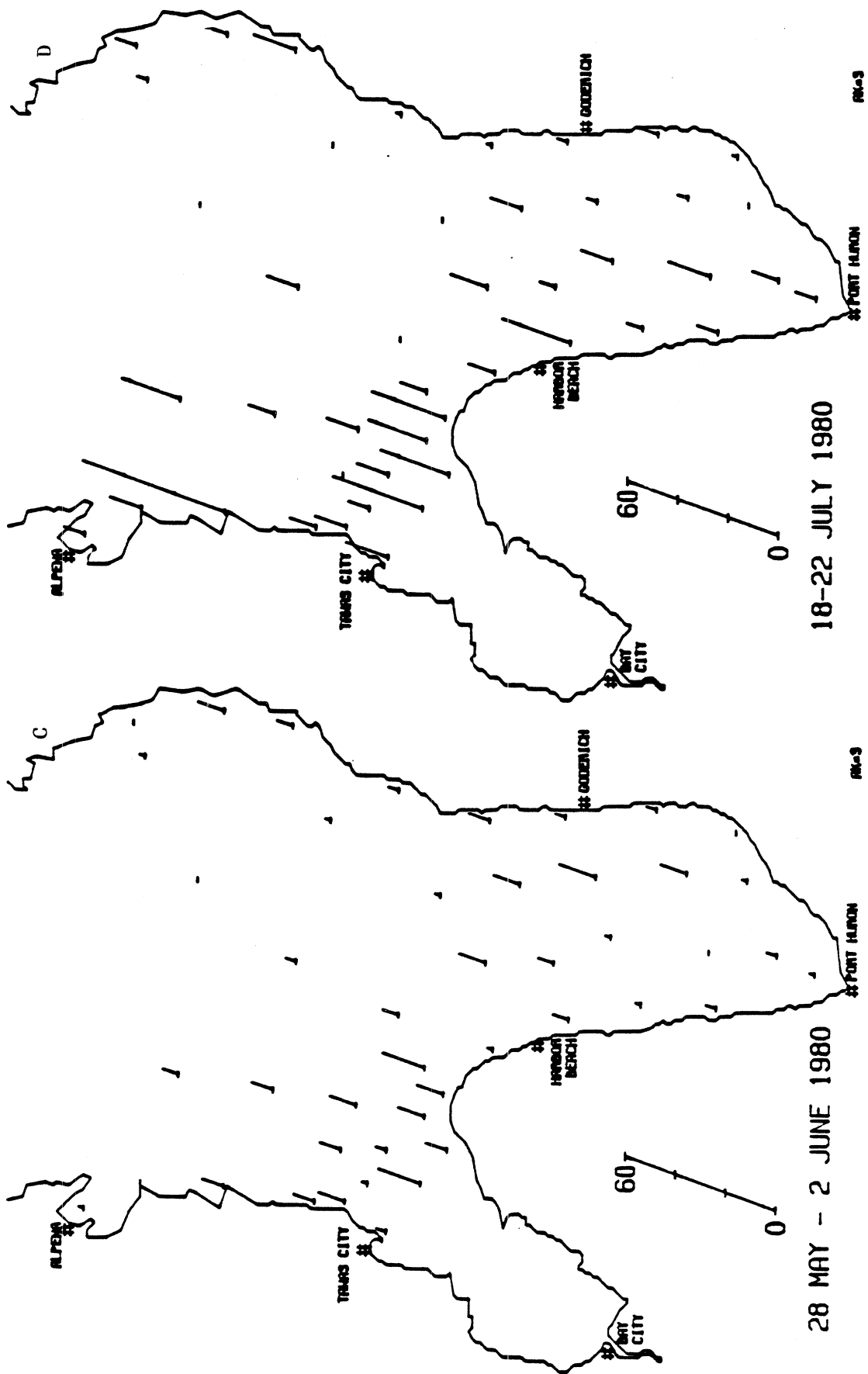


FIG. 37. (continued)

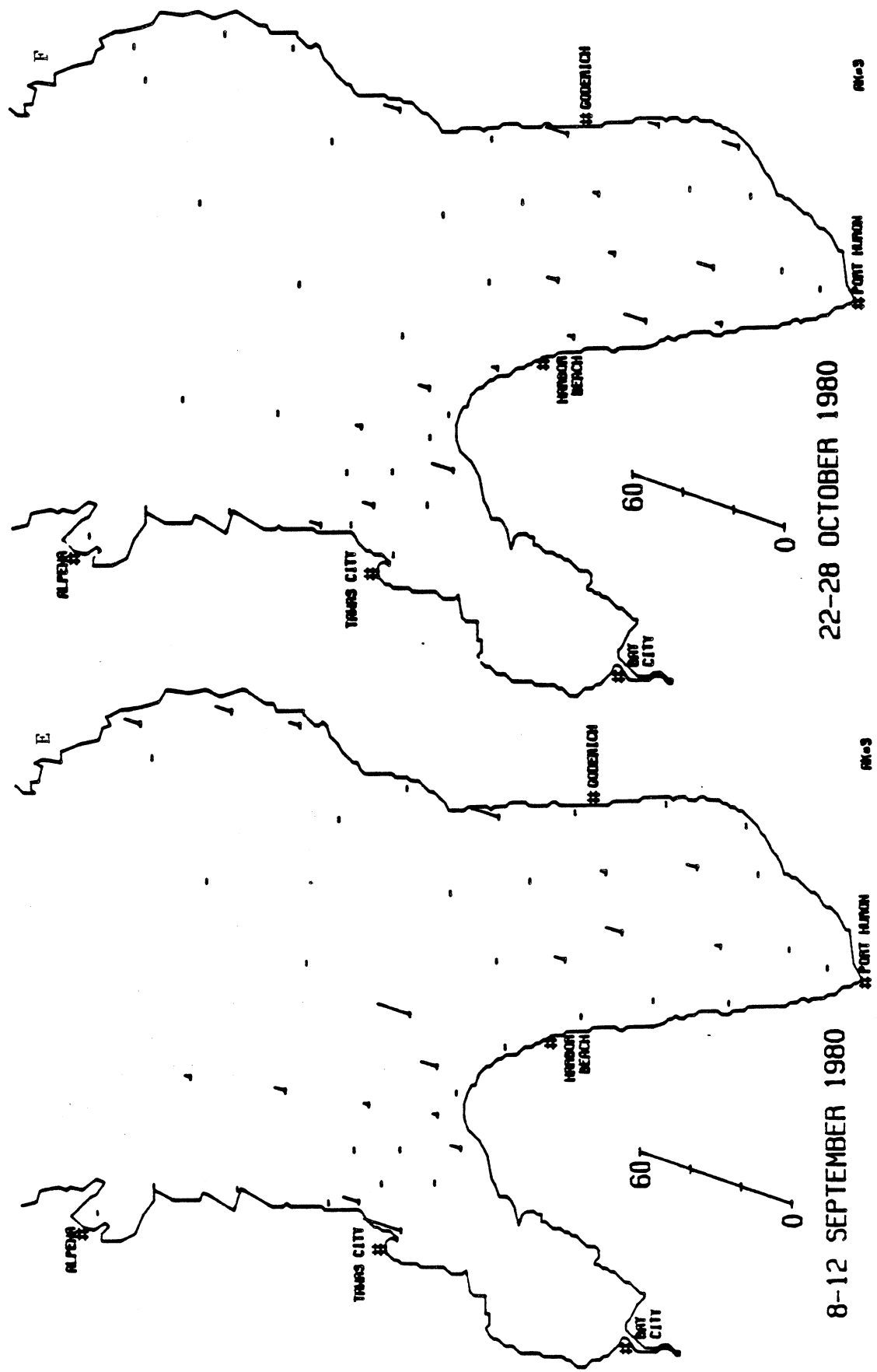


FIG. 37. (continued)

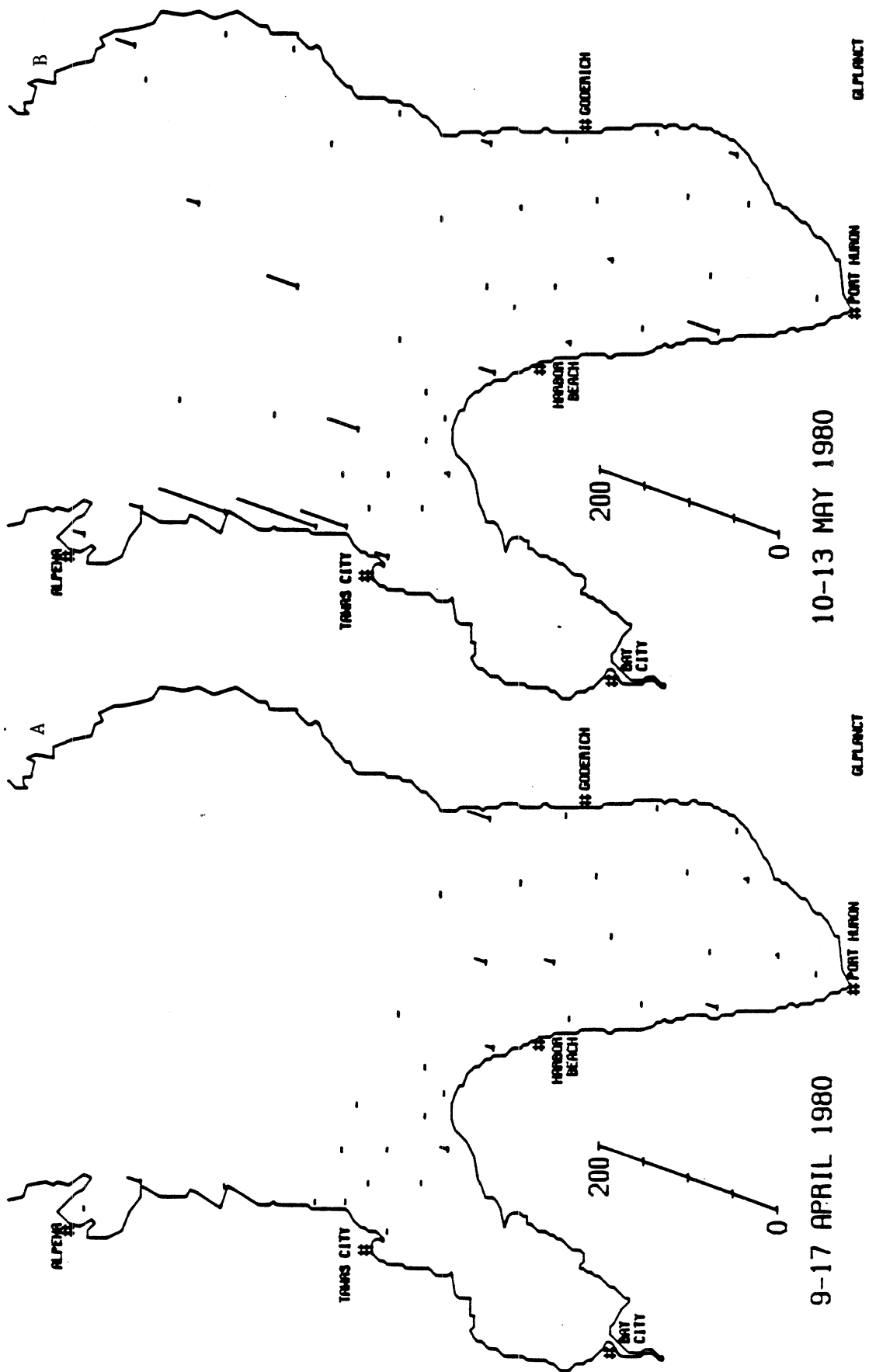


FIG. 38. Distribution of *Gloeocystis planctonica*.

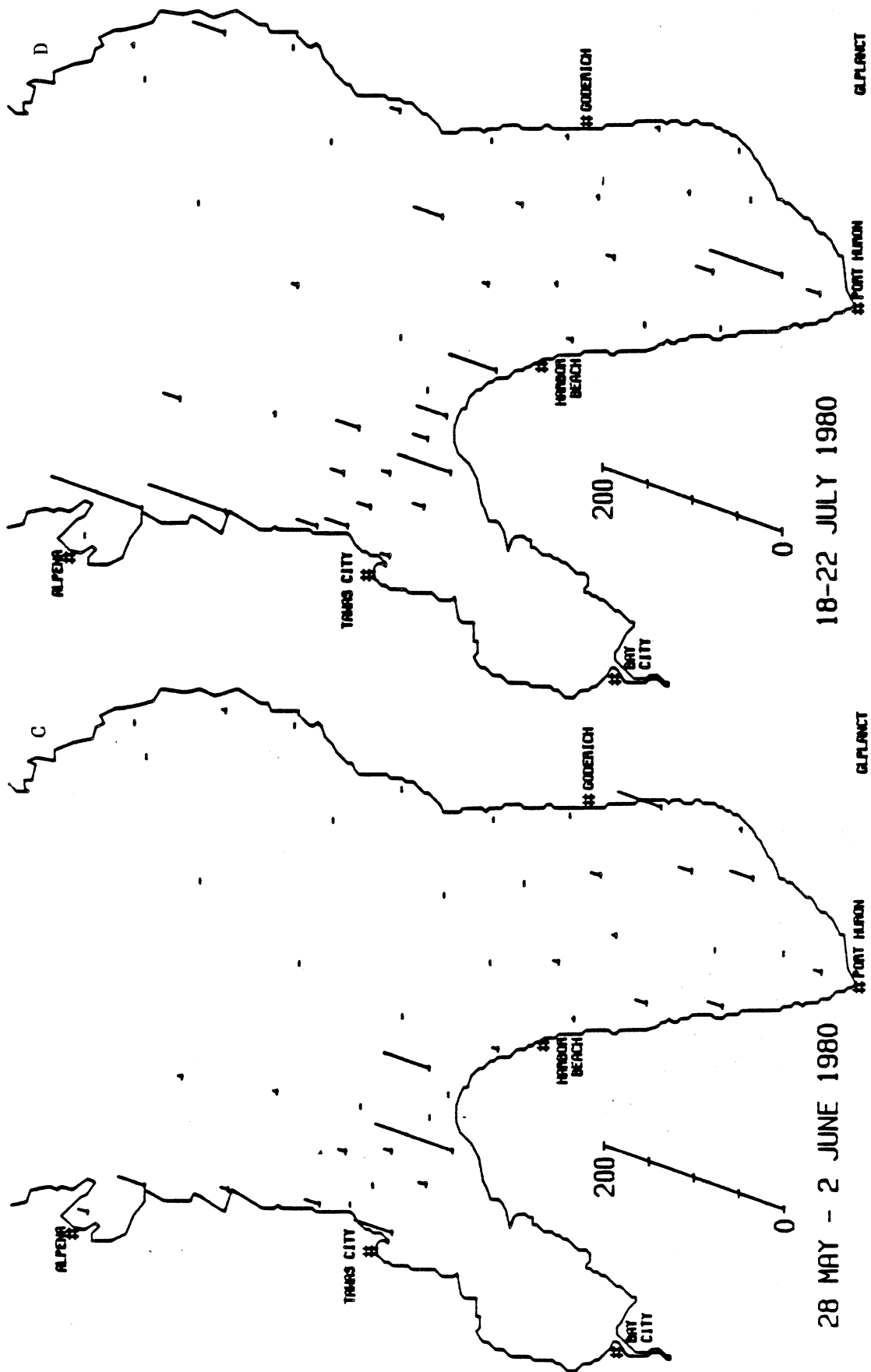


FIG. 38. (continued)

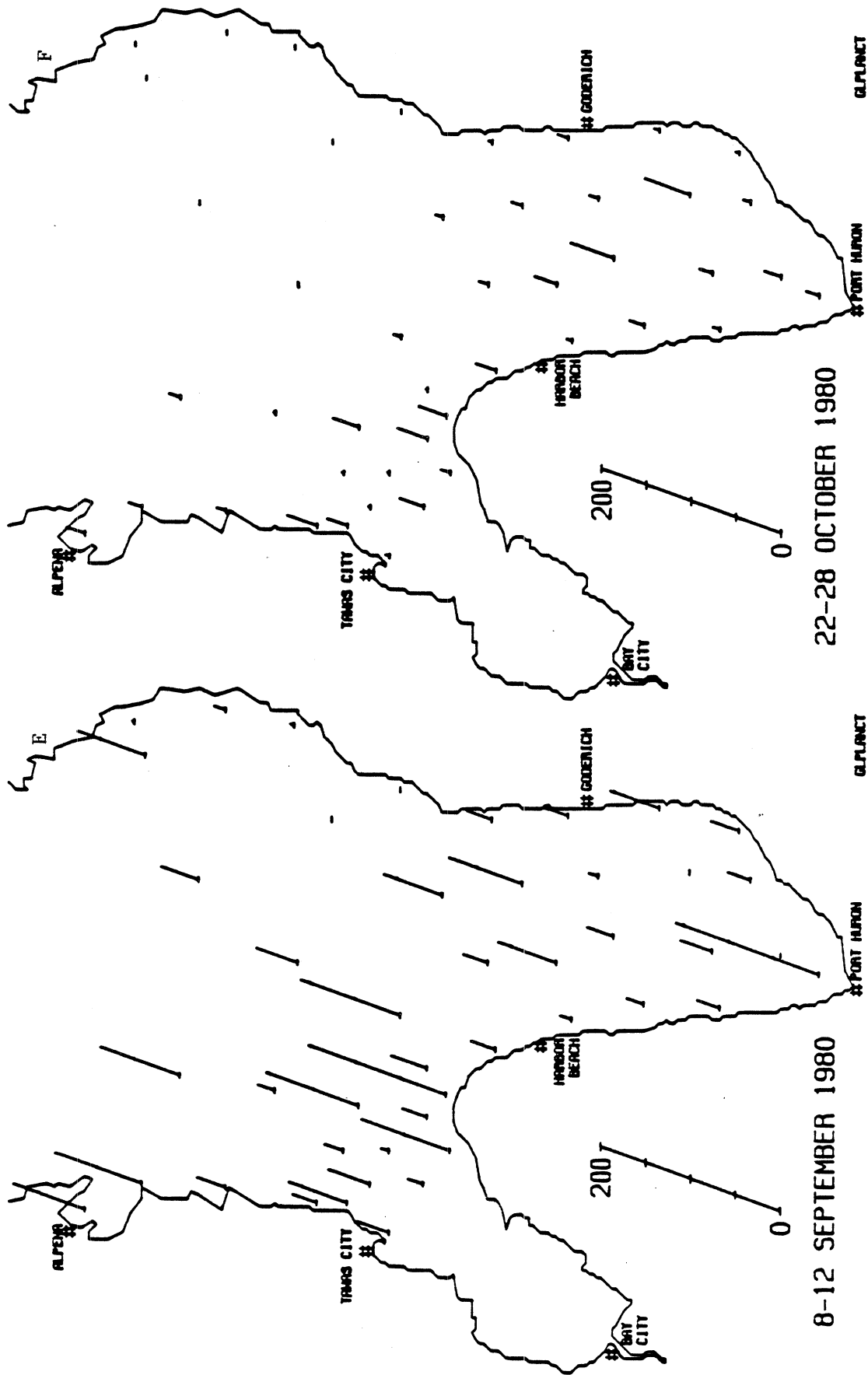


FIG. 38. (continued)

concentrations north of Tawas City in the nearshore zone. In June (Fig. 38C), this species showed a wider distribution, especially in the southern basin, with highest abundances near Saginaw Bay. During July (Fig. 38D), large peaks were observed south of Alpena. However, numerous occurrences were recorded near Saginaw Bay. Greatest abundance for the season was recorded in September (Fig. 38E). Highest cell densities were seen in the Saginaw Bay interface, at Alpena, and at Port Huron. However, distribution was erratic during this month. In October (Fig. 38F), abundance was greatly reduced but it was distributed throughout the study area excepting the northeastern sector.

Gloeotila sp.--

Due to its small diameter (approximately 2  $\mu\text{m}$ ) and varying internal cell structure, this filamentous alga has not been placed at the specific level. It was previously observed in southern Lake Huron during 1974 (Stoermer and Kreis 1980). In April (Fig. 39A), highest abundances were noted in the offshore area of the southern basin. During May (Fig. 39B), it was absent from the open waters of the central basin but had highest abundances in the Canadian nearshore zone. In June (Fig. 39C), it was widely distributed throughout the study area but in no apparent pattern. From July through October (Figs. 39D-39F), very low abundances were recorded, usually from the central basin.

Scenedesmus quadricauda--

This colonial green alga is commonly reported from the plankton of small inland lakes. It is one of the most frequently reported species of this genus from the Great Lakes. As most green algae in the Great Lakes, it reaches its greatest abundance during the summer in enriched areas. In April (Fig. 40A),

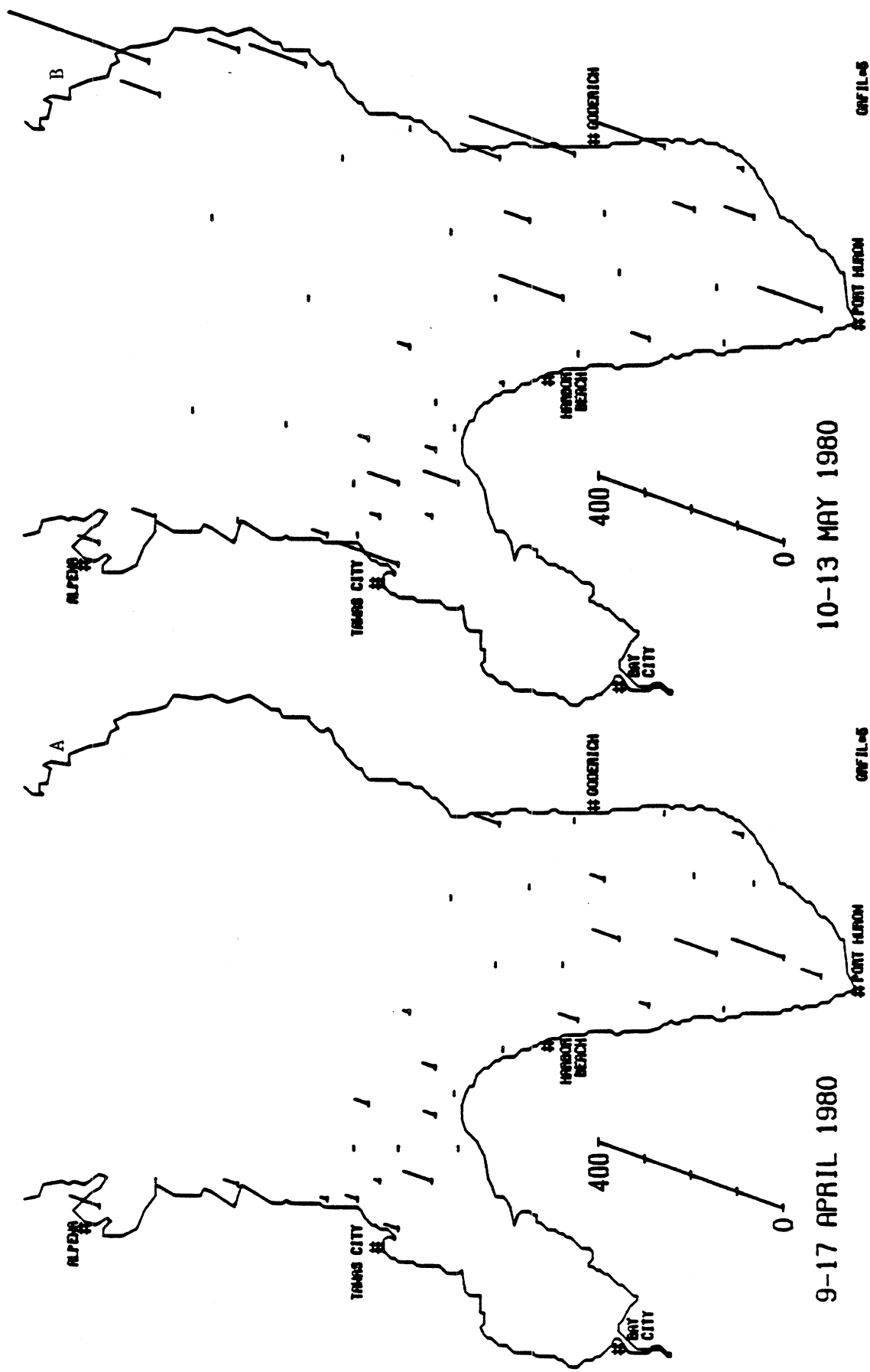


FIG. 39. Distribution of *Gloeotilla* sp.

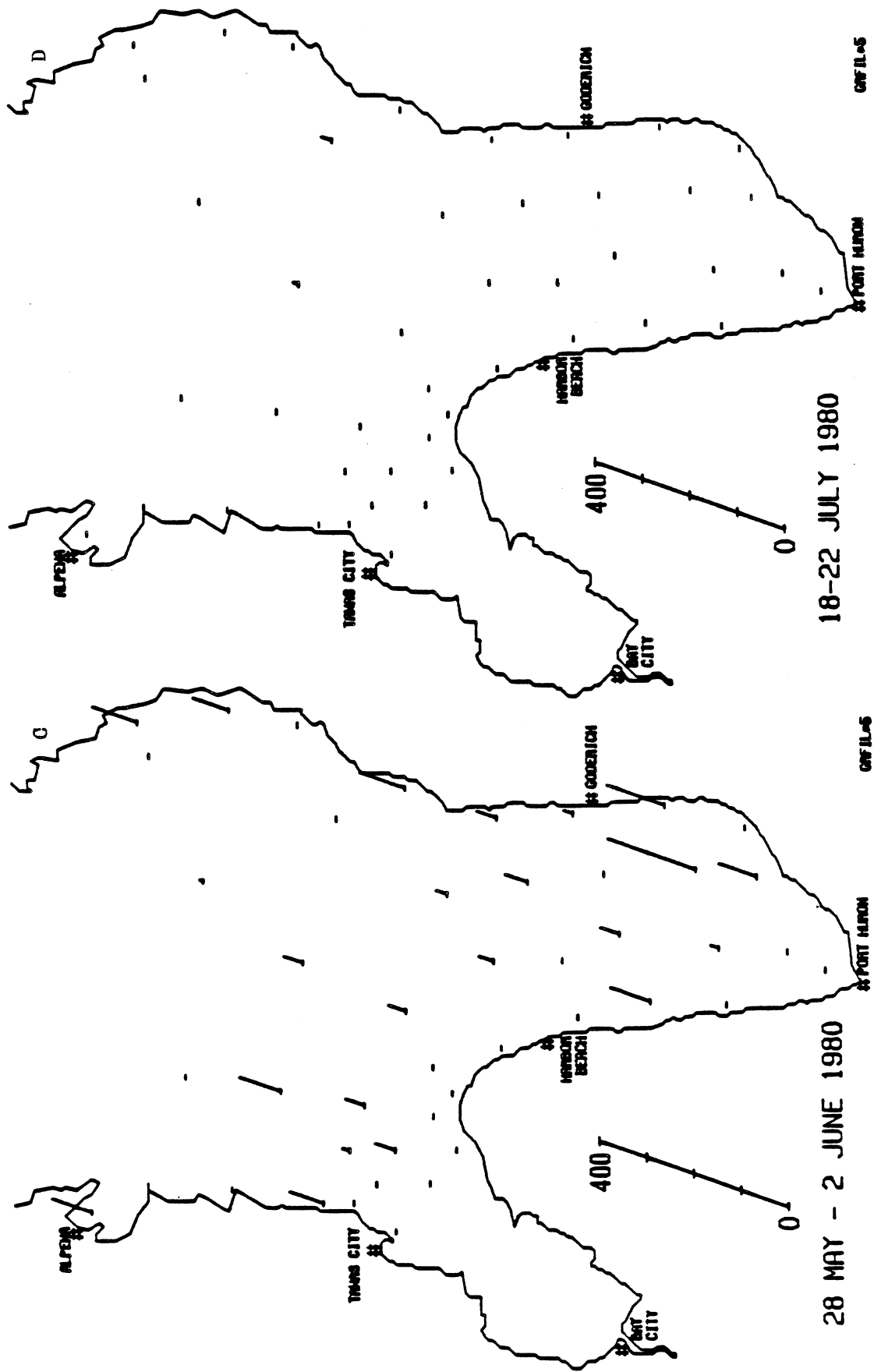


FIG. 39. (continued)

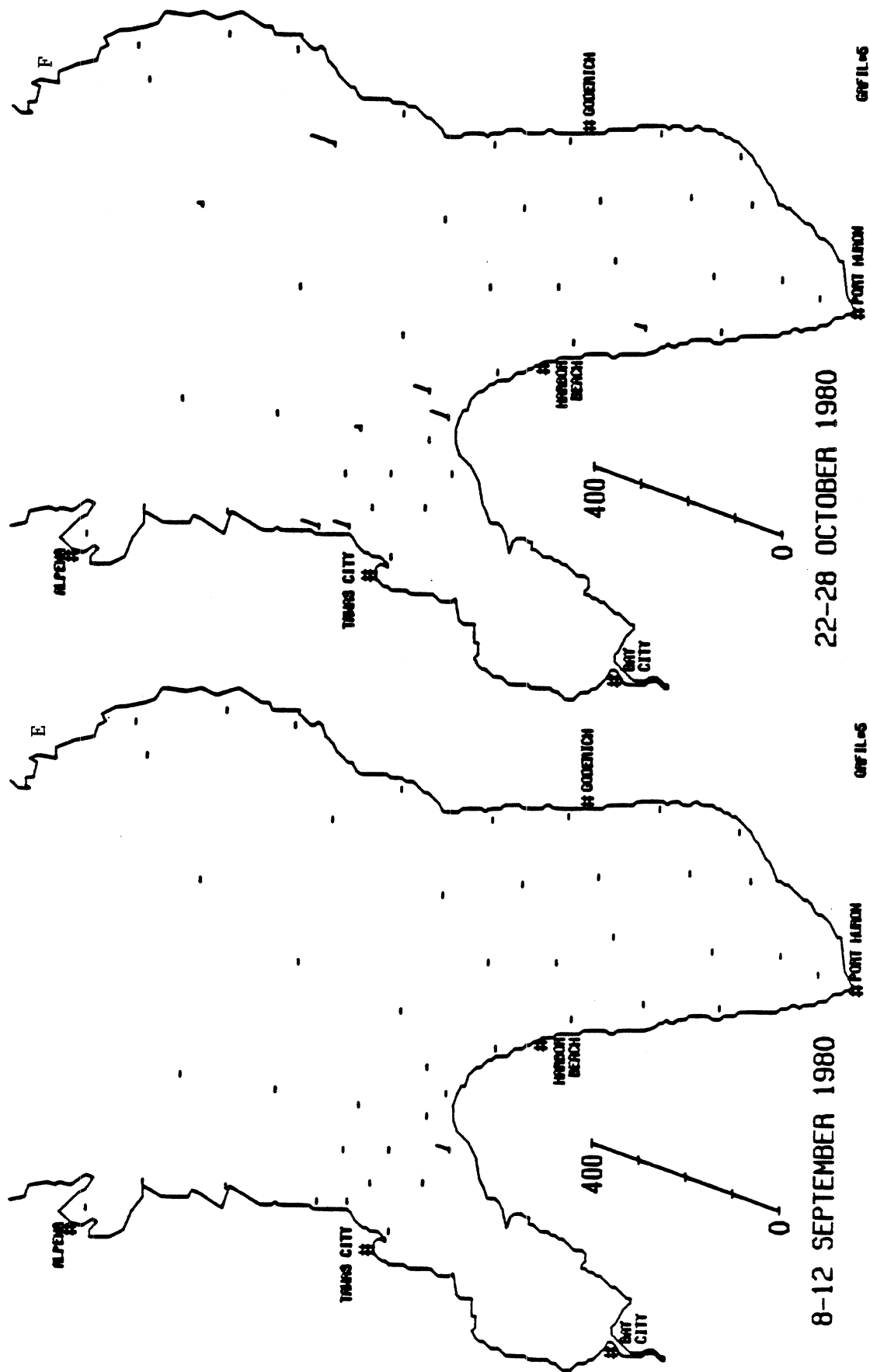


FIG. 39. (continued)

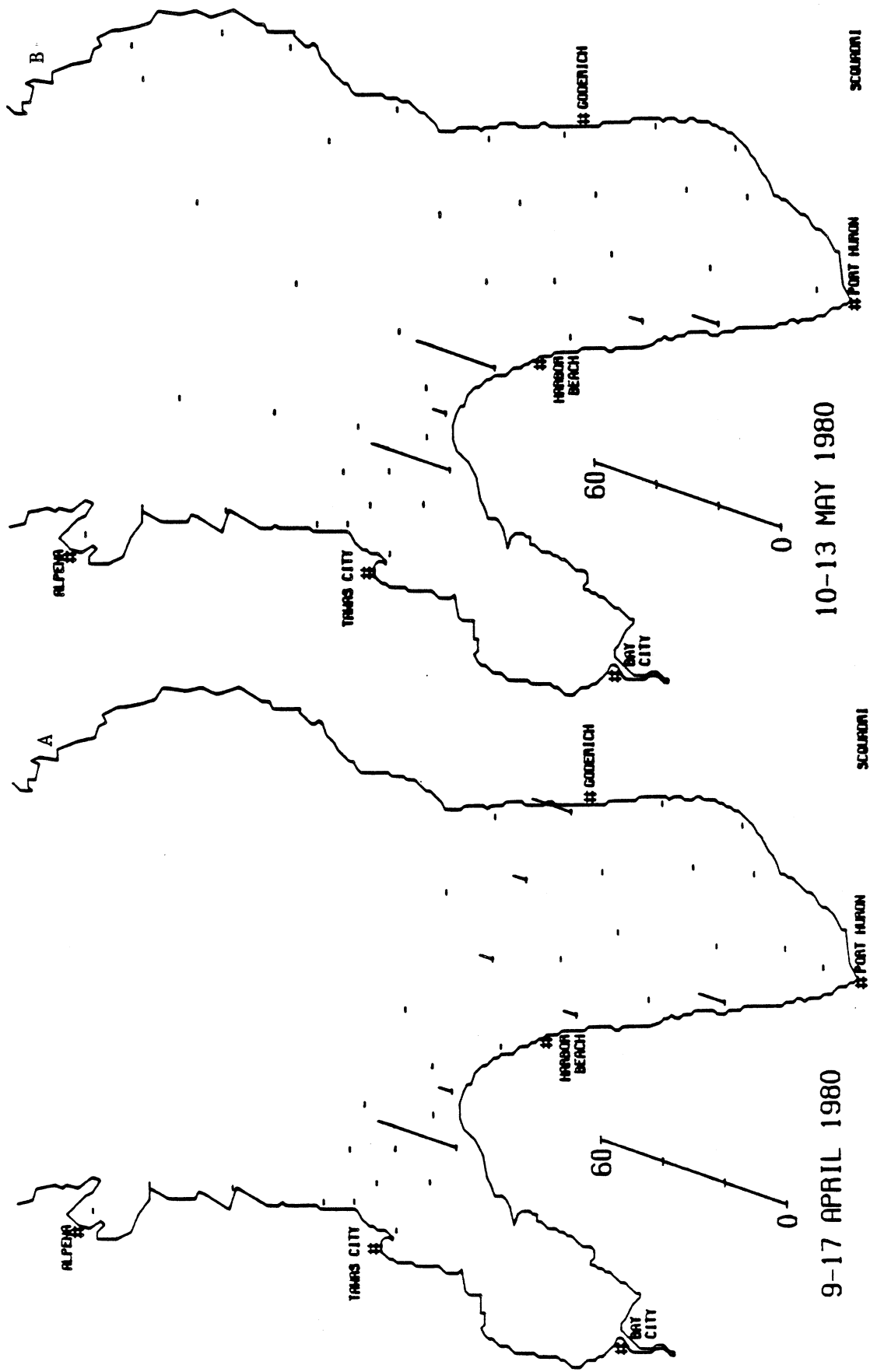


FIG. 40. Distribution of *Scenedesmus quadricauda*.

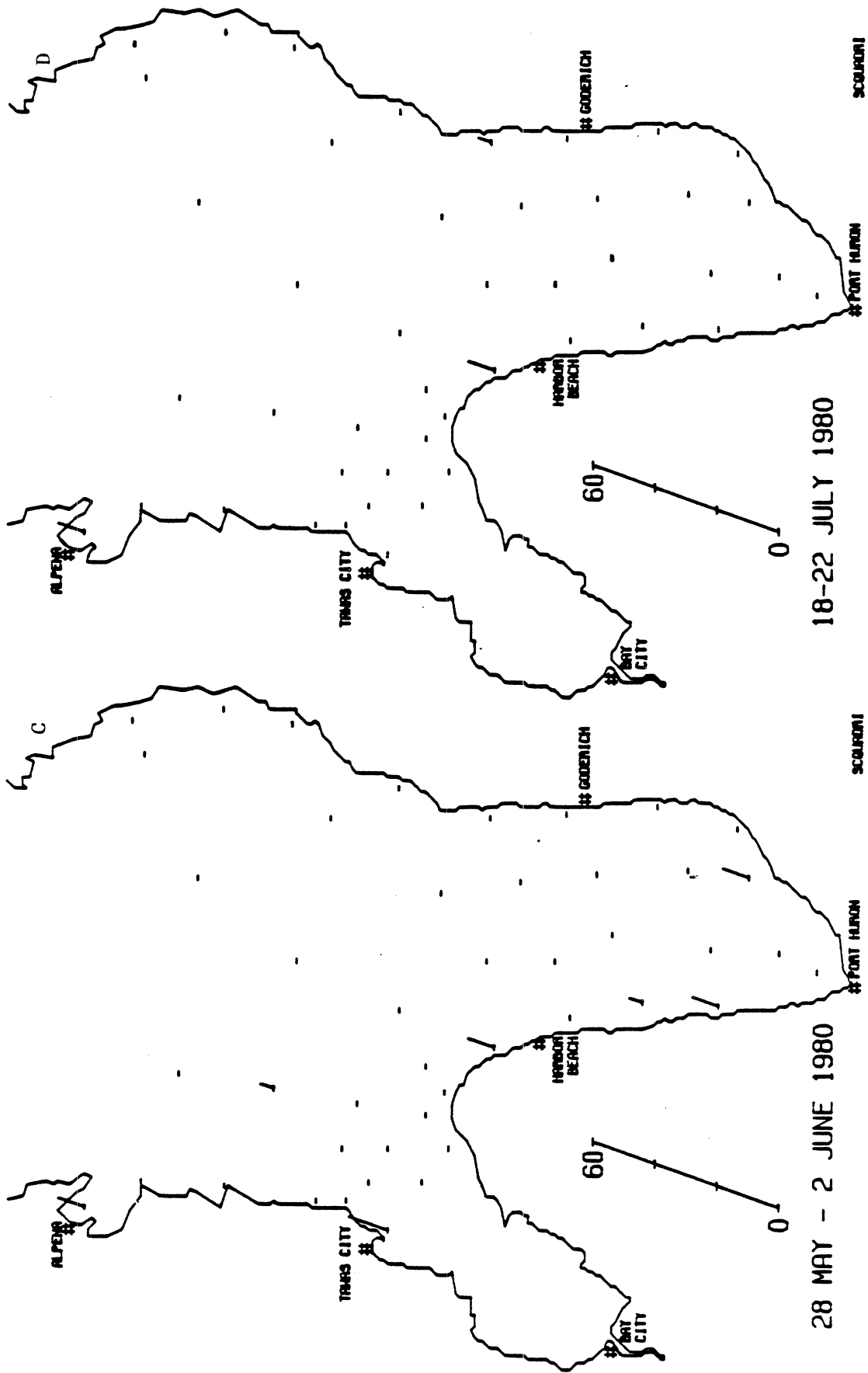


FIG. 40. (continued)

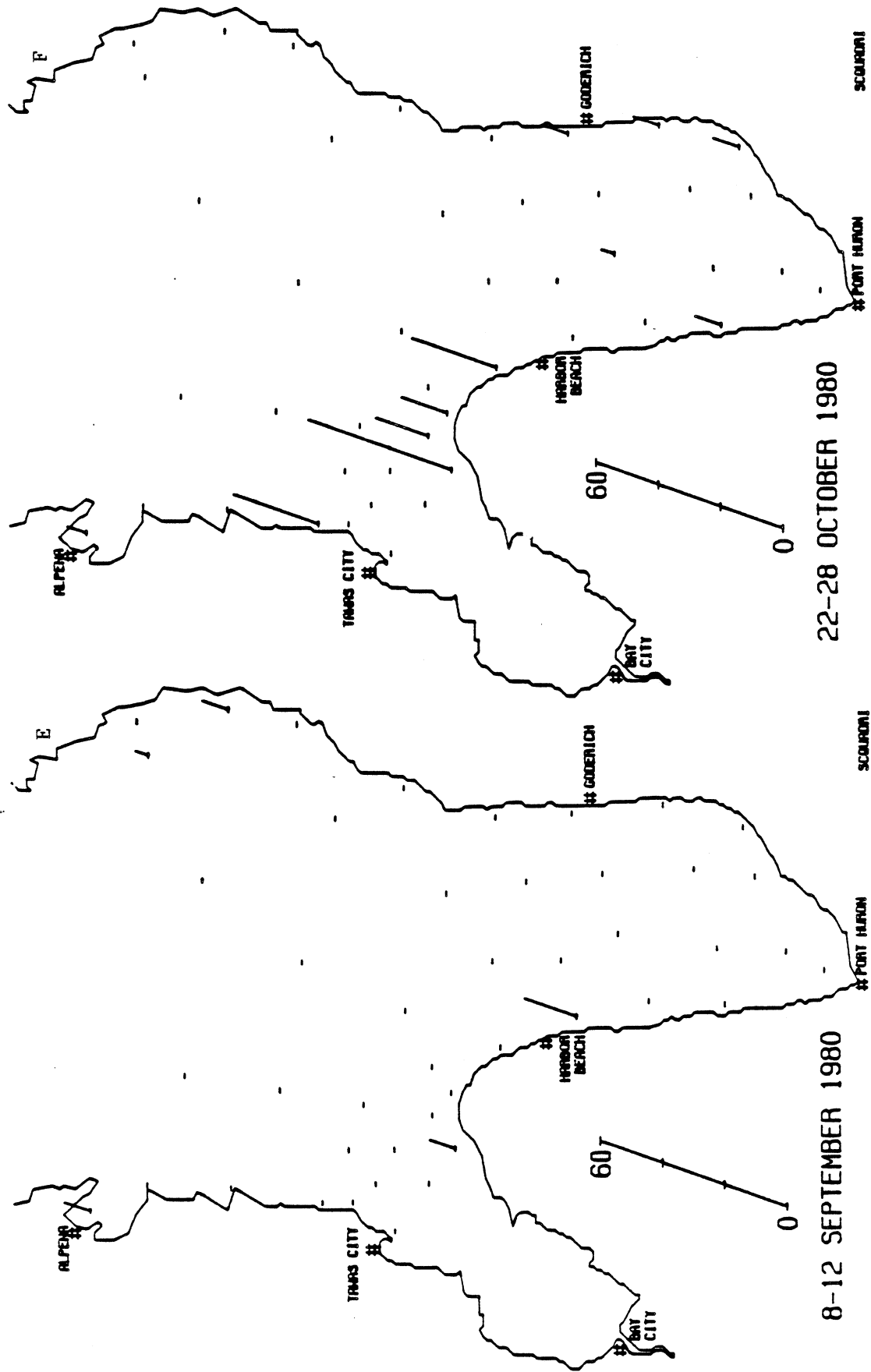


FIG. 40. (continued)

greatest concentrations were observed in outer Saginaw Bay with several sporadic occurrences in the southern basin. During May (Fig. 40B), highest cell numbers were again observed in outer Saginaw Bay and just south of the bay. Occurrences were restricted to the U.S. nearshore zone of the southern basin. Sporadic occurrences at low abundance were seen along the entire U.S. shoreline in June through September (Figs. 40C-40E). During October (Fig. 40F), it reached its greatest abundance in outer Saginaw Bay and south of the bay. Occurrences were also observed between Alpena and Tawas City and in the Canadian nearshore zone of the southern basin.

#### Cyanophyta - Blue-greens

Massive water blooms of blue-green algae are generally considered to be indicative of eutrophic conditions (Hutchinson 1967). For the Great Lakes, this observation is generally correct, with large blue-green abundances reported in Saginaw Bay (Stoermer et al. 1982), Green Bay (Stoermer and Stevenson 1979), and the western end of Lake Erie (Munawar and Munawar 1976). However, the situation is complicated in the upper Great Lakes by the occurrence, sometimes in substantial abundances, of blue-greens which find their primary habitat in the offshore plankton during the silicate-limited period in the fall. This particular case demonstrates the need for taxonomic identification to the species level in order to properly assess trophic conditions. During this study, both colonial and filamentous forms were observed in southern Lake Huron. However, most species present are not associated with eutrophic conditions. Quantitative estimates of blue-green algae are sometimes misleading due to their colonial and filamentous habits; their tendency to bloom also creates patchy distributions.

From April through June (Figs. 41A-41C), blue-green algae were widely distributed over the study area in uniformly low abundances. Greatly reduced occurrences and abundances were observed in July (Fig. 41D). July values were the lowest seasonal values recorded. During September (Fig. 41E), blue-greens dramatically increased in abundance and this period included the highest single and average values for the season. Greatest abundance was observed in the Saginaw Bay interface and waters just south of the bay. Large abundances were also observed in Thunder Bay and the nearshore zone south of Alpena. Comparatively lower numbers of blue-greens occurred in the eastern half of the lake, particularly in the Canadian coastal zone. Abundances were slightly less in October (Fig. 41F) but remained relatively high. Abundances were more uniformly distributed than in September; however, very low values were again observed for the entire Canadian nearshore zone.

Anabaena flos-aquae--

This blue-green alga reaches its greatest abundance in areas of the Great Lakes which have been eutrophied. It is the only blue-green species reported in 1980 which is usually associated with enriched conditions. A. flos-aquae may form conspicuous water blooms and is commonly noted in the summer plankton of inland lakes of the Great Lakes states (Prescott 1962). It is also the only heterocystous blue-green reported in this study. Its filaments occur in large, entangled masses and, due to the presence of gas-filled pseudovacuoles, are usually seen in greatest numbers in the upper epilimnion. In this study, A. flos-aquae was not observed until July when it was recorded in low abundances in Thunder Bay and south of Goderich (Fig. 42A). It was observed in Thunder Bay, the mid-southern basin, and the northeast sector of the study

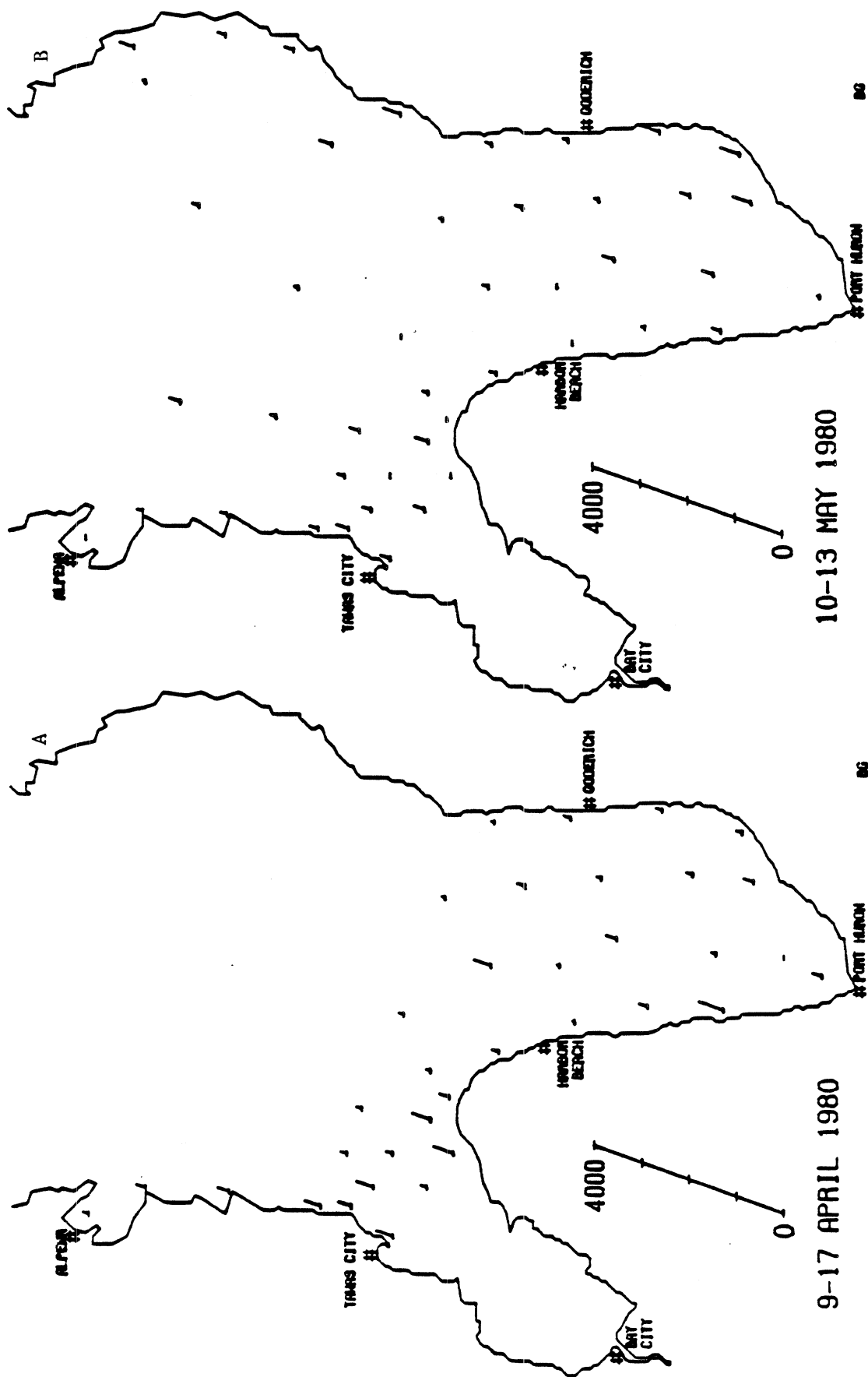


FIG. 41. Seasonal distribution and abundance trends (cells/mL) of blue-green algae, 1980.

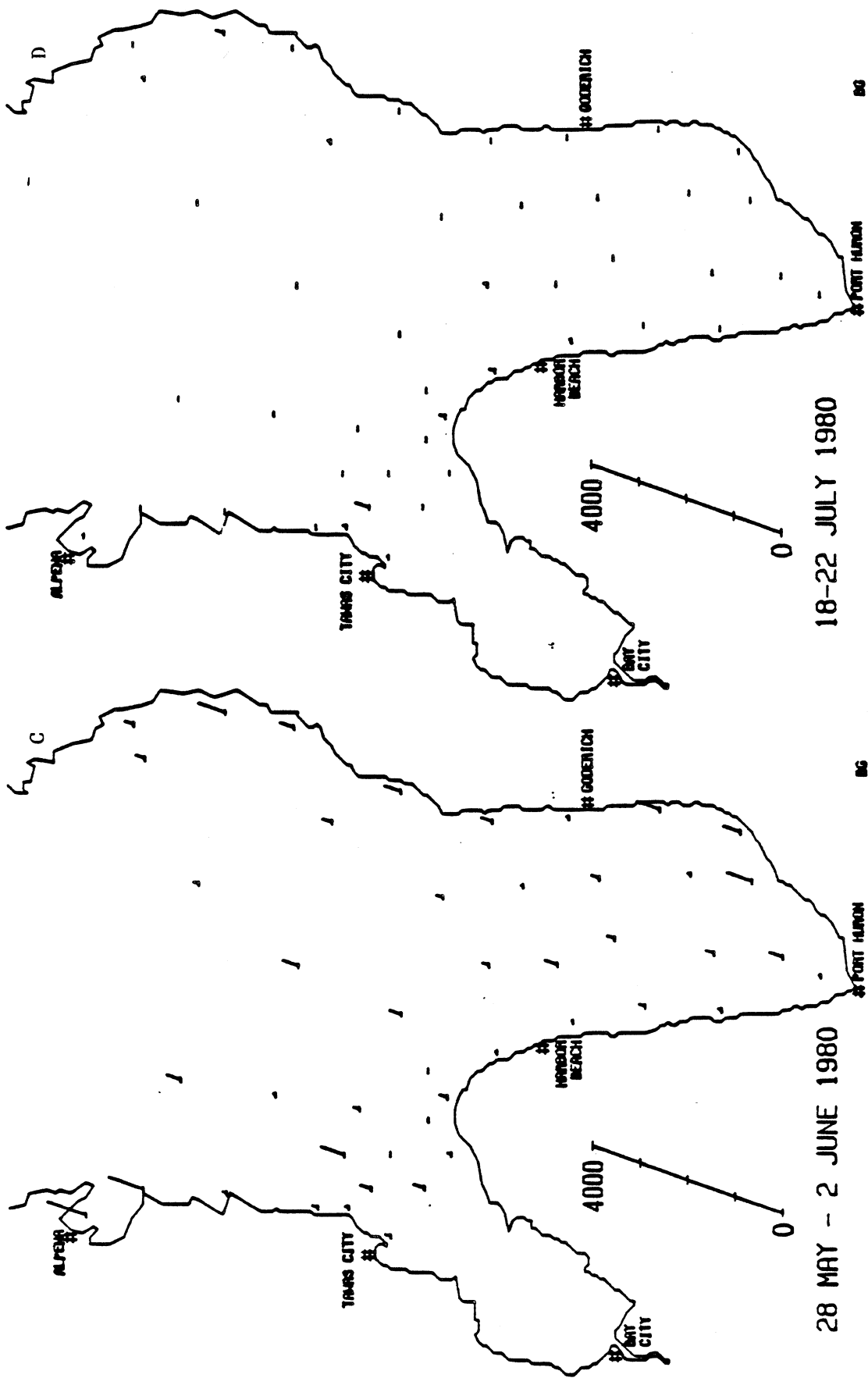


FIG. 41. (continued)

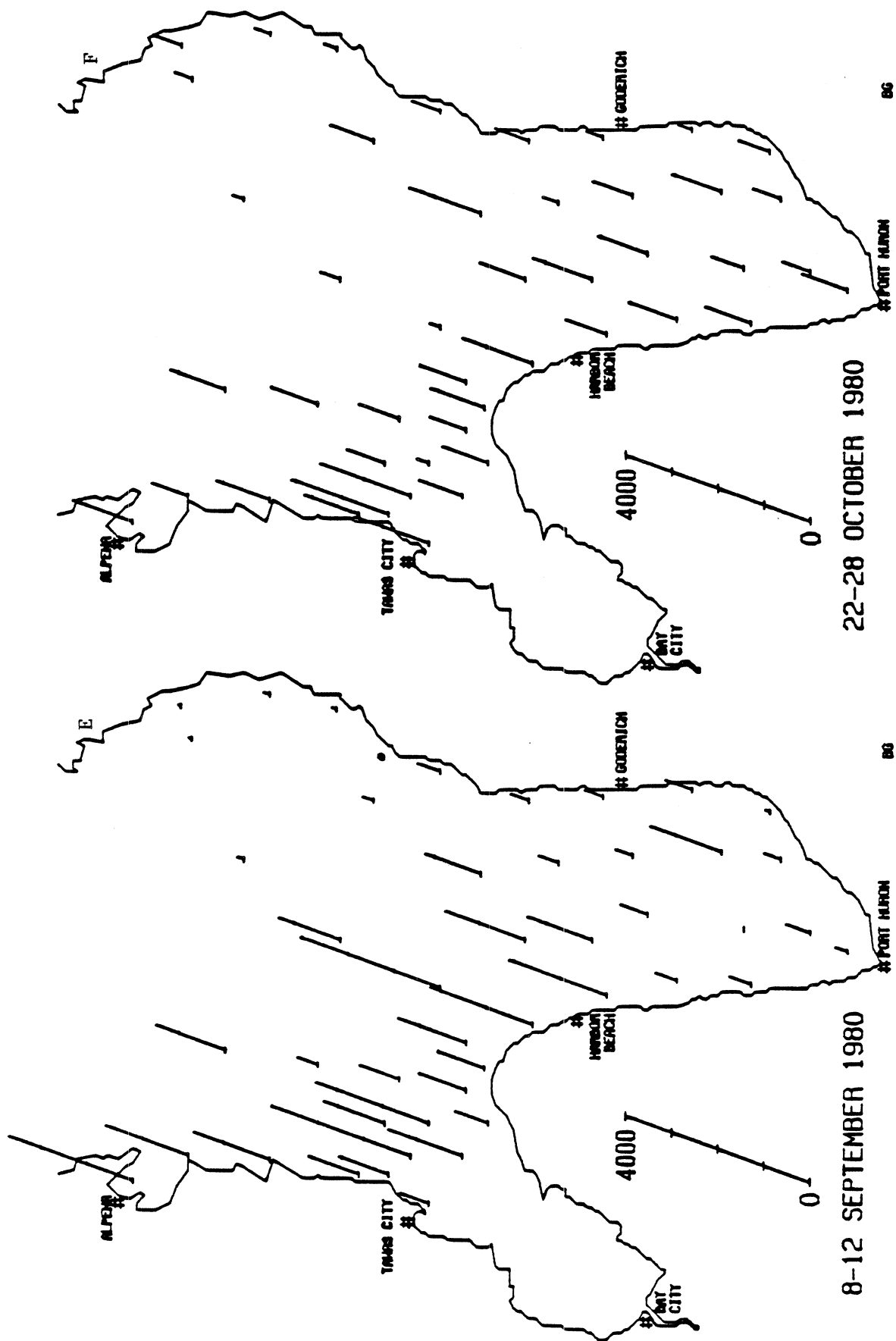


FIG. 41. (continued)

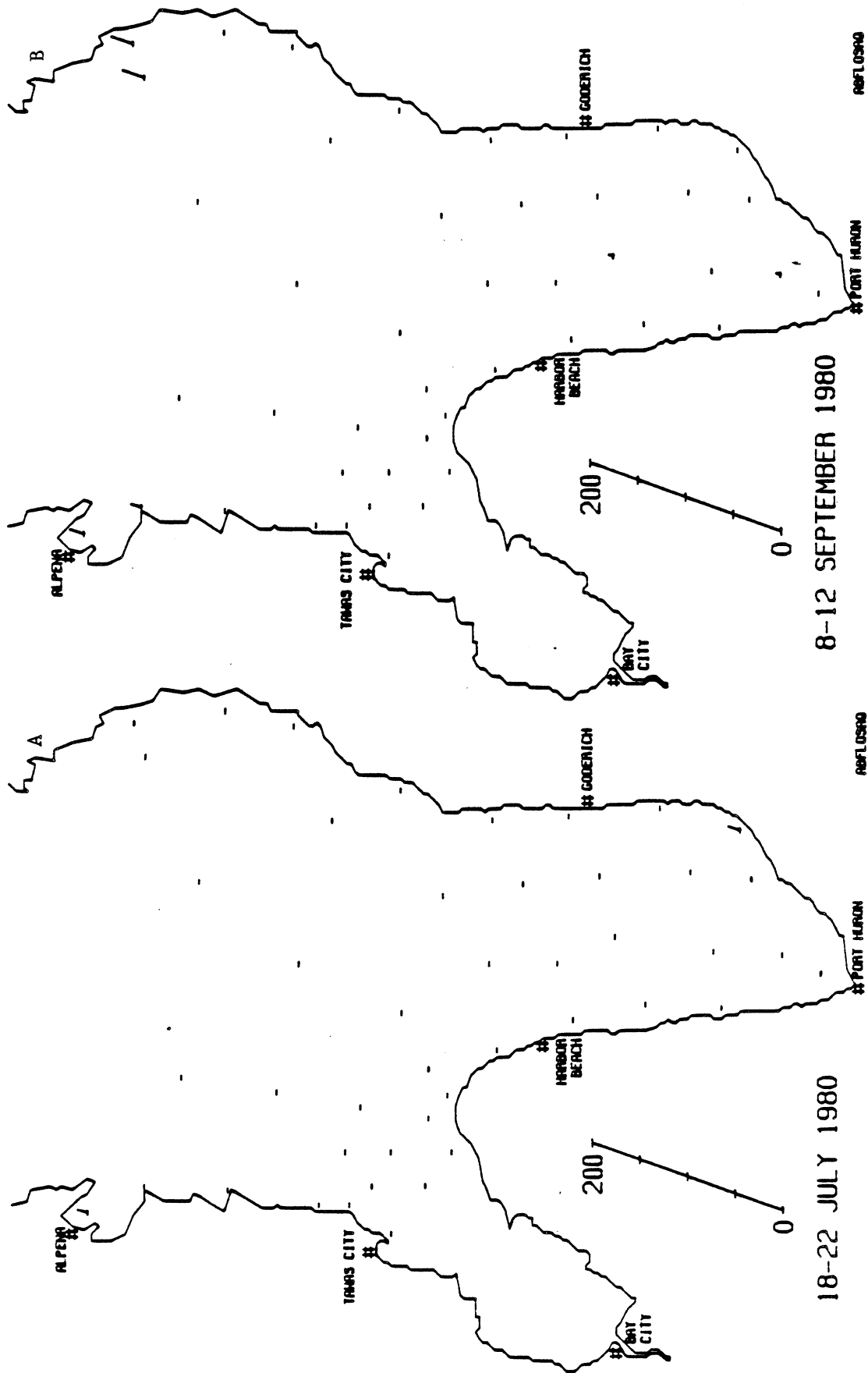


FIG. 42. Distribution of *Anabaena flos-aquae*.

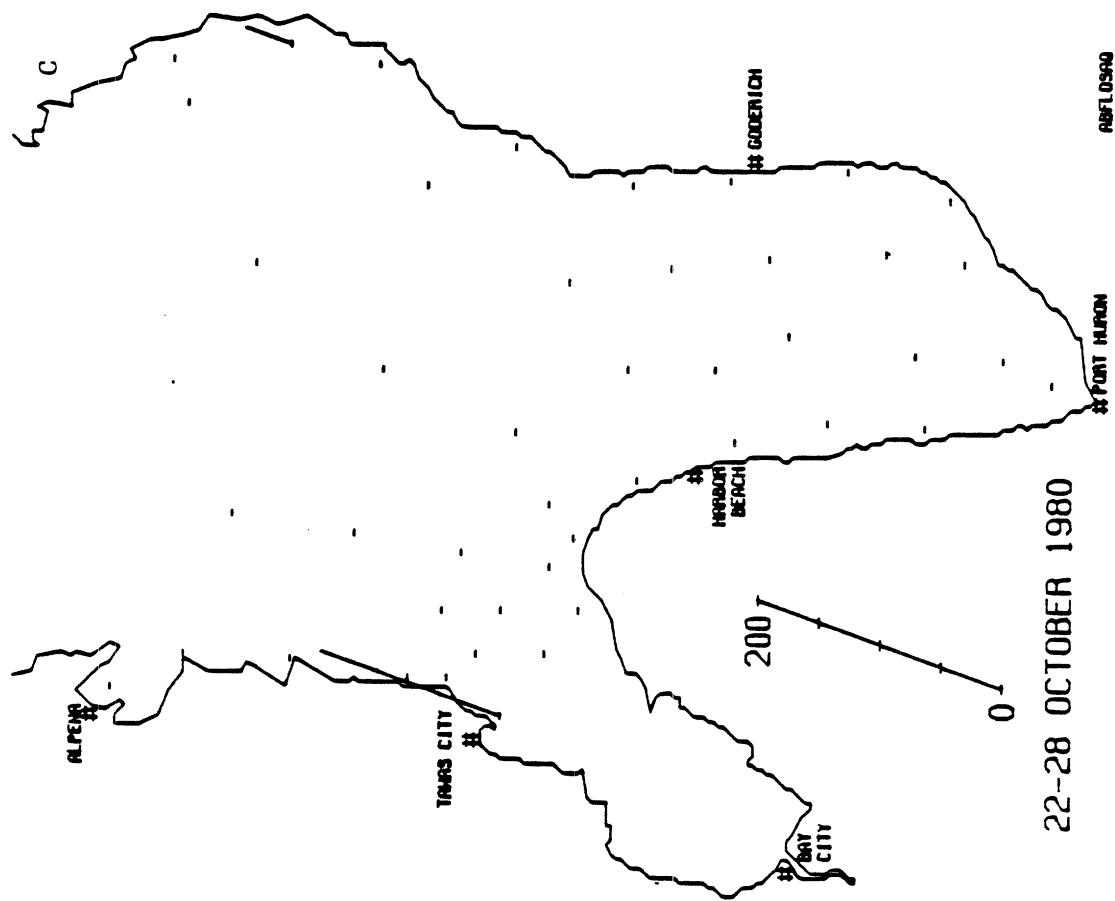


FIG. 42. (continued)

area in September (Fig. 42B). It reached its greatest abundance at Tawas City in October (Fig. 42C) and was also observed on the northern Canadian coast.

Anacystis incerta--

This taxon is commonly observed in the offshore waters of the upper Great Lakes during the fall. During this study, it reached its greatest abundance in the fall and was, on average, the most abundant blue-green alga. A. incerta occurs in colonial form, generally with 100-500 individuals enclosed in a mucilaginous matrix. From April through July (Figs. 43A-43D), abundances were very low with sporadic occurrences. This population reached its greatest abundance in September (Fig. 43E), especially in the Saginaw Bay-Lake Huron interface waters and in the upper sector of the southern basin. Reduced cell numbers and an erratic distribution were observed in October (Fig. 43F).

Anacystis thermalis--

As the other member of this genus just discussed, this taxon exhibits highest abundance during the fall months. However, A. thermalis usually occurs in small colonies of four to eight individuals. From April through July (Figs. 44A-44D), this species showed very low abundances and no apparent distributional pattern. It reached its greatest abundance during September (Fig. 44E) in the Saginaw Bay interface waters and in the northern basin, particularly in the U.S. sector. In October (Fig. 44F), abundances were reduced and fairly uniformly distributed over the study area.

Gomphosphaeria lacustris--

This colonial blue-green is commonly observed during the late summer and fall in the upper Great Lakes. It usually does not form conspicuous water

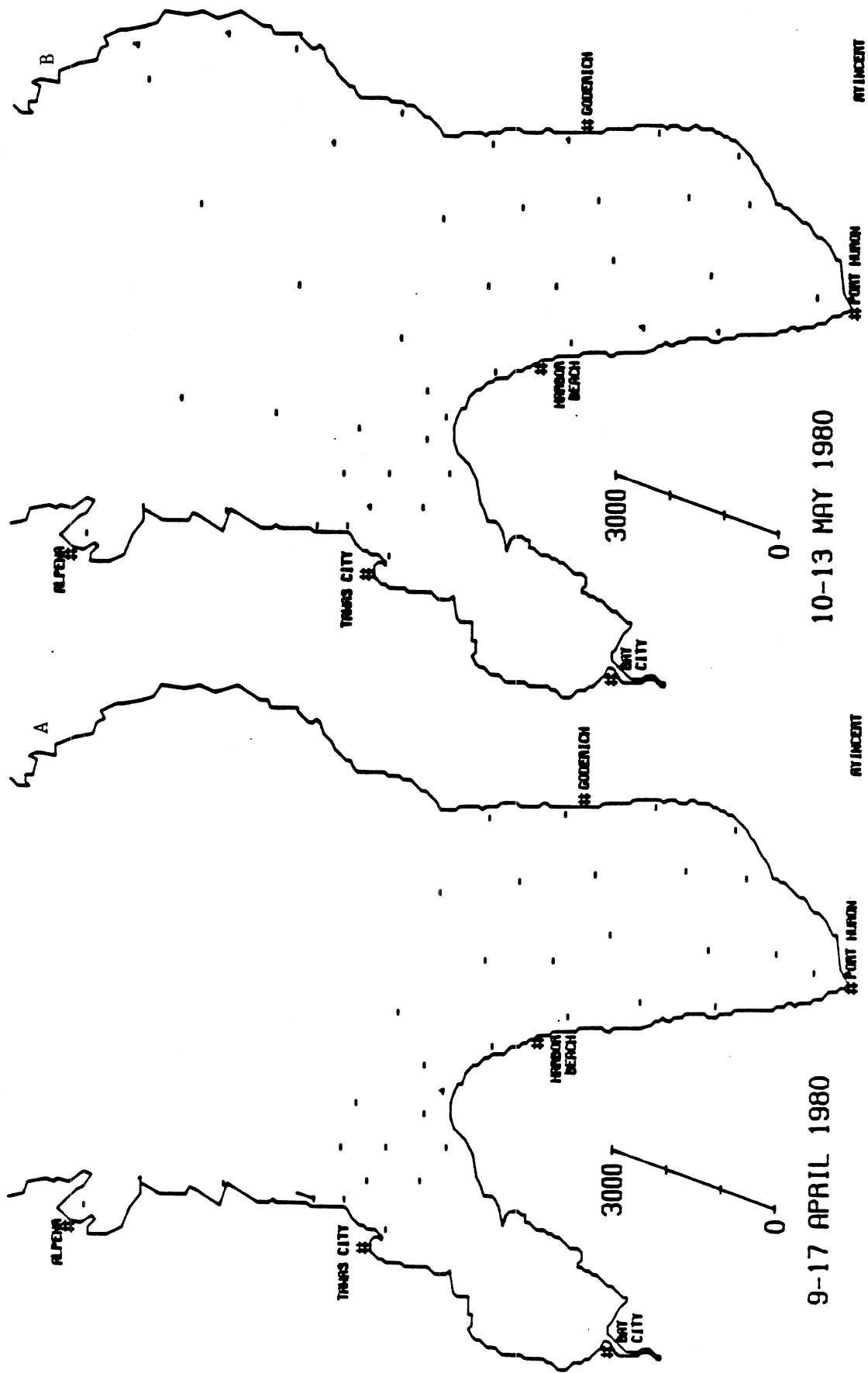


FIG. 43. Distribution of *Anacystis incerta*.

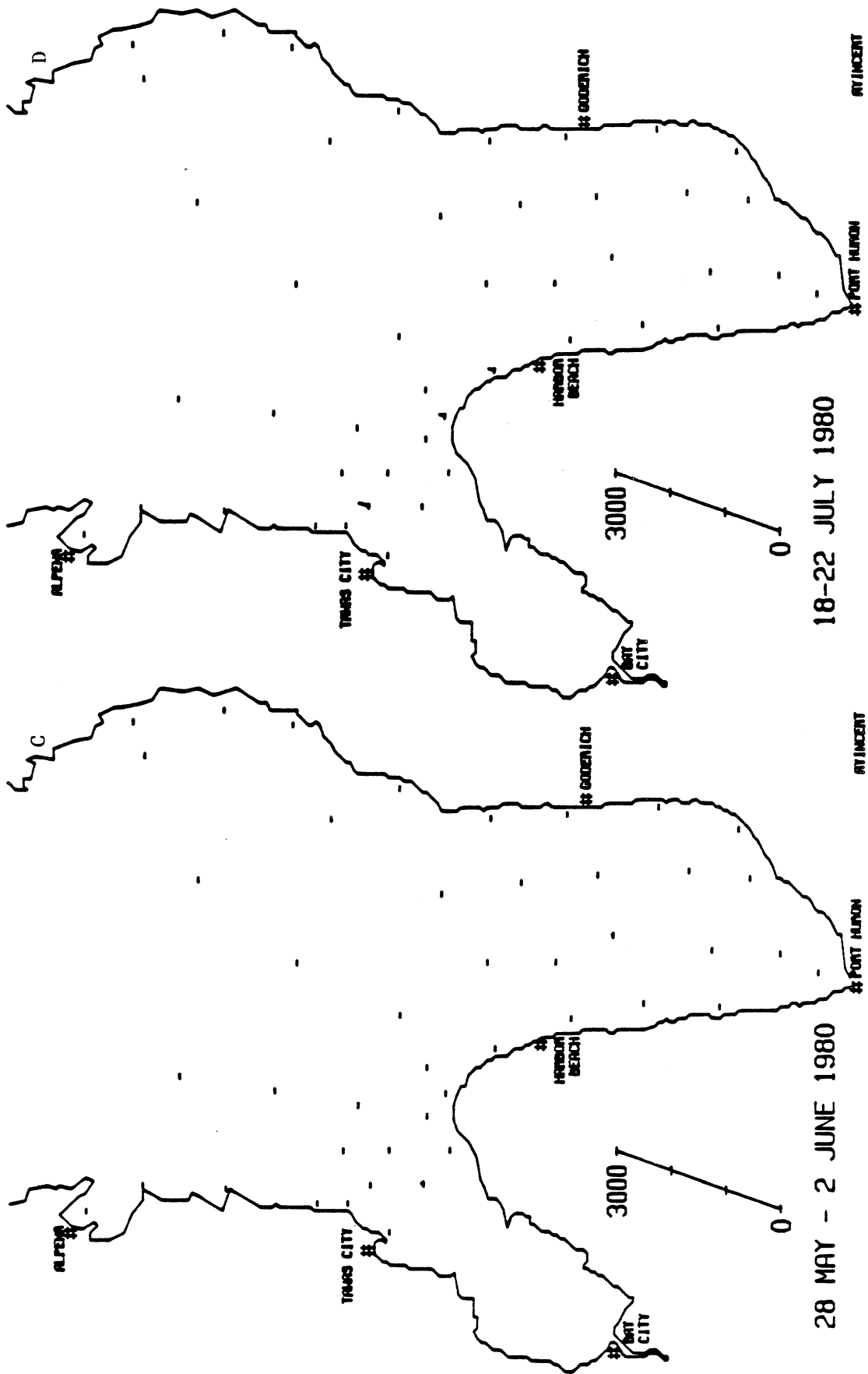


FIG. 43. (continued)

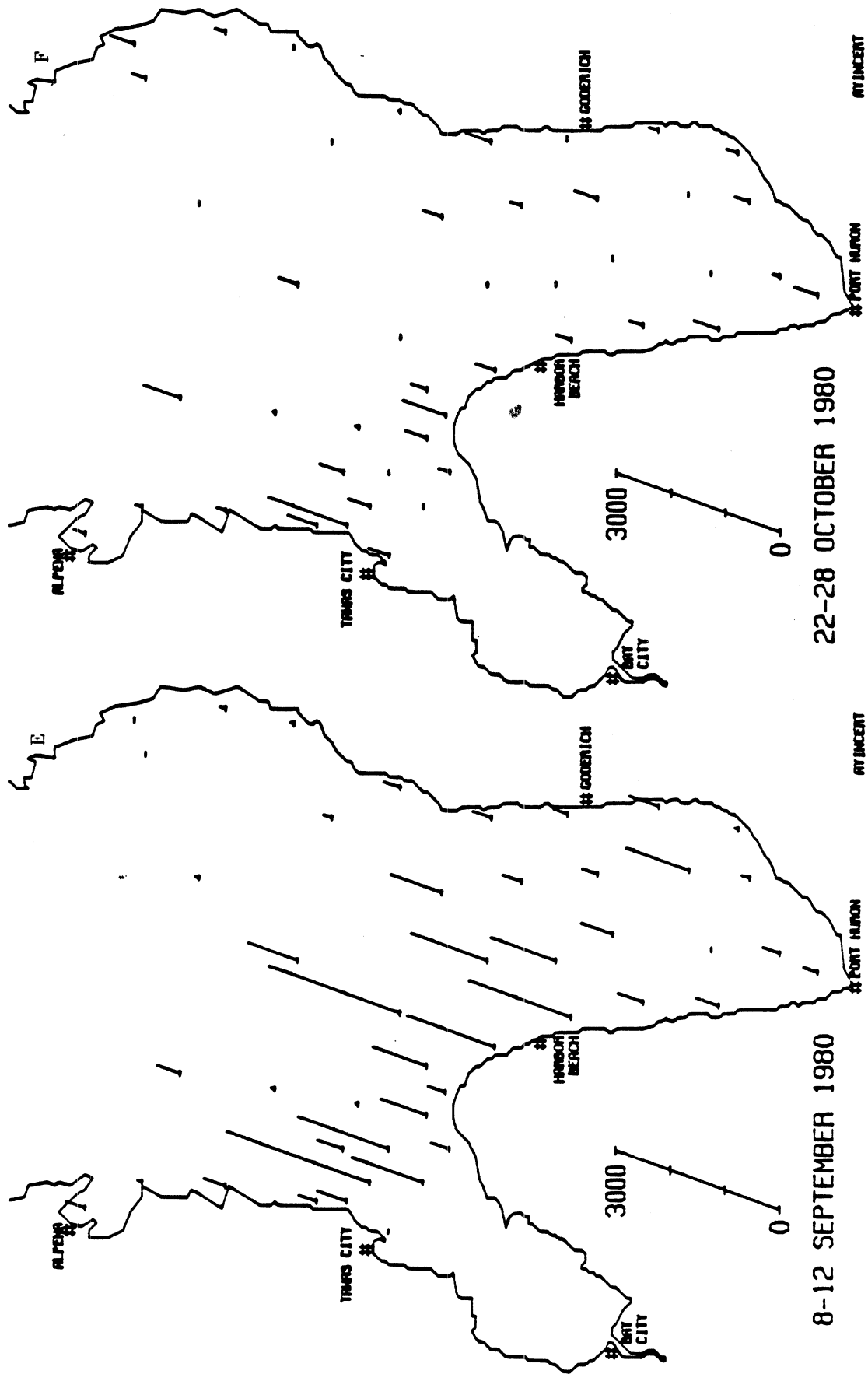


FIG. 43. (continued)

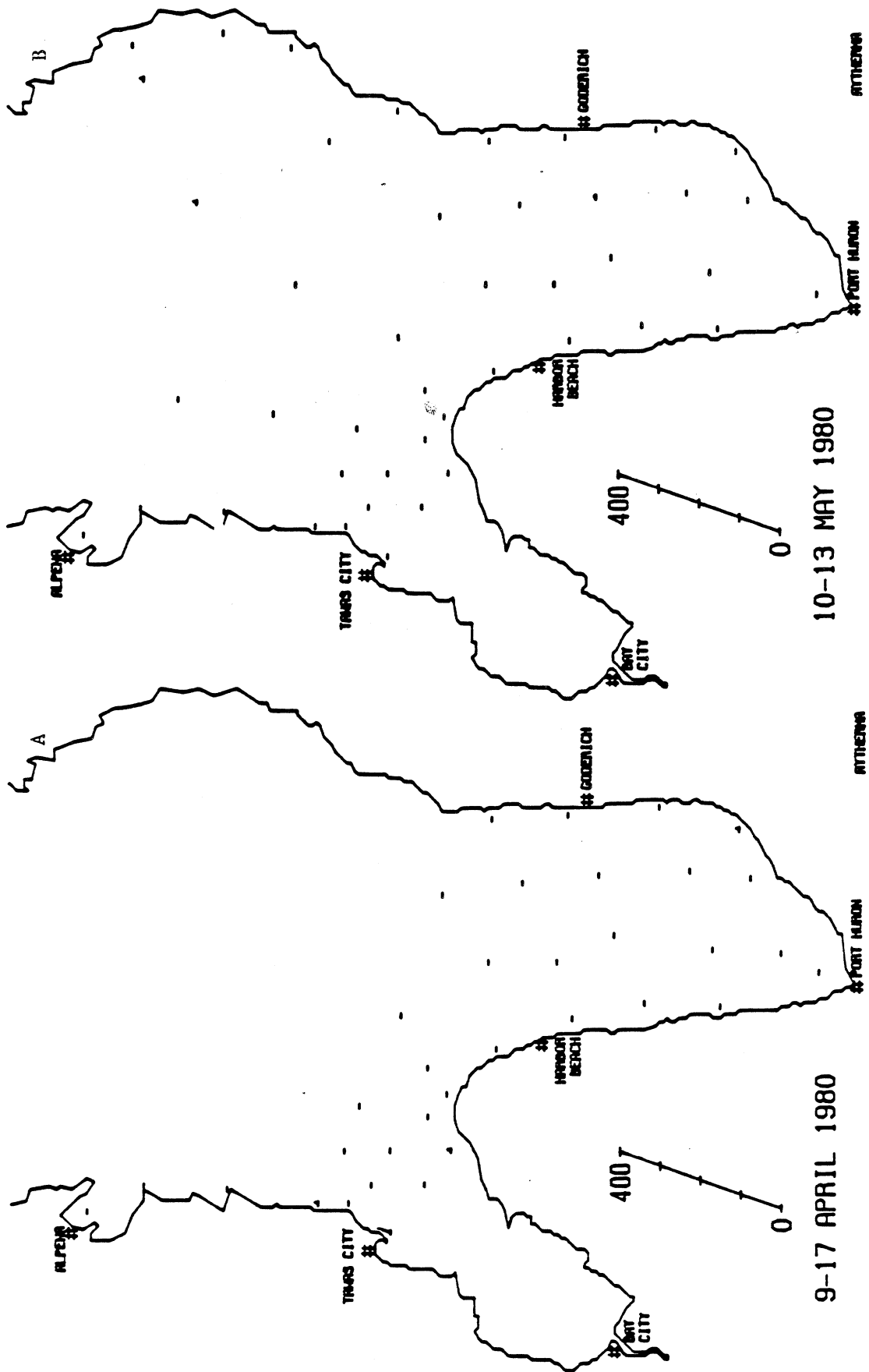


FIG. 44. Distribution of *Anacystis thermalis*.

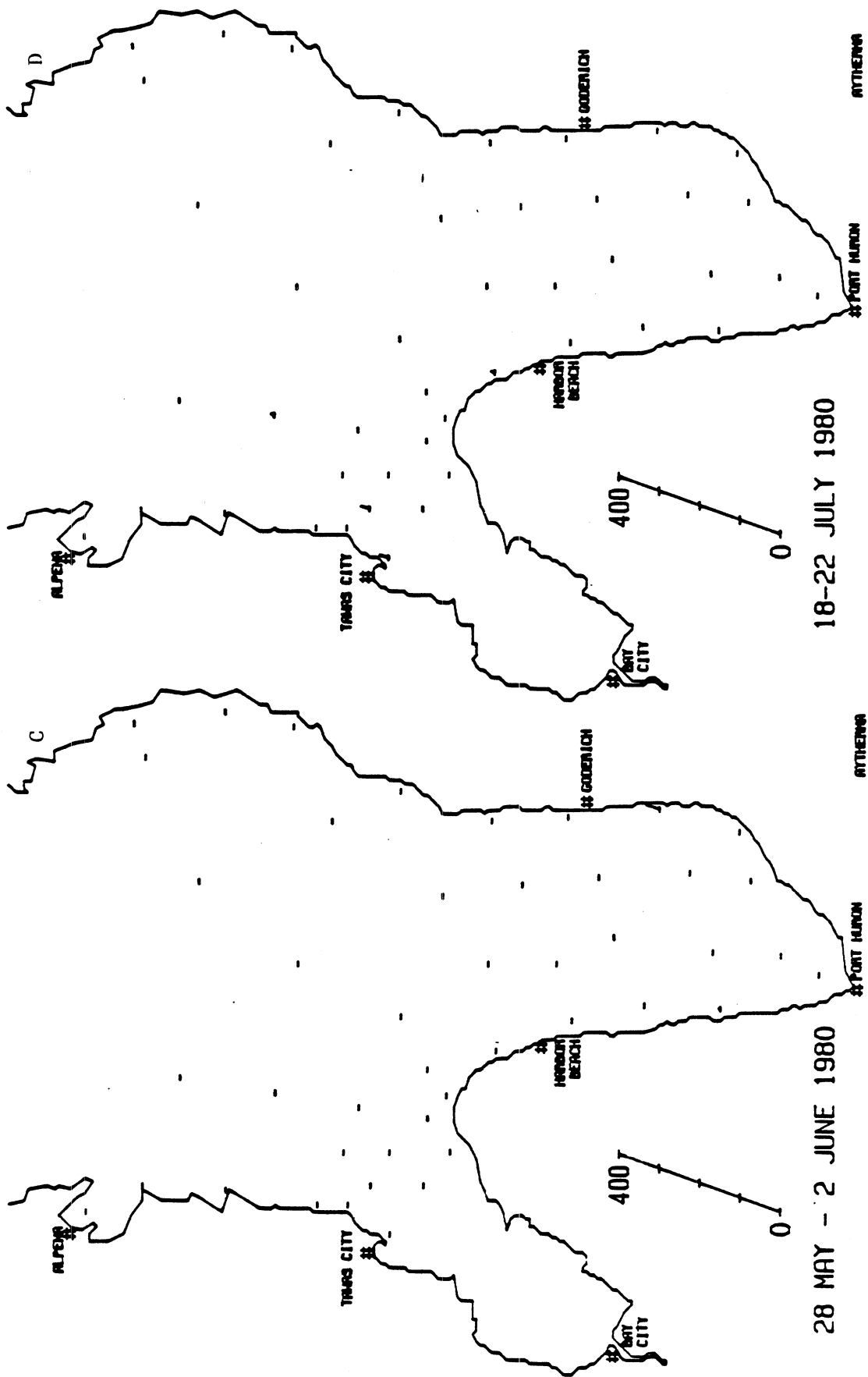


FIG. 44. (continued)

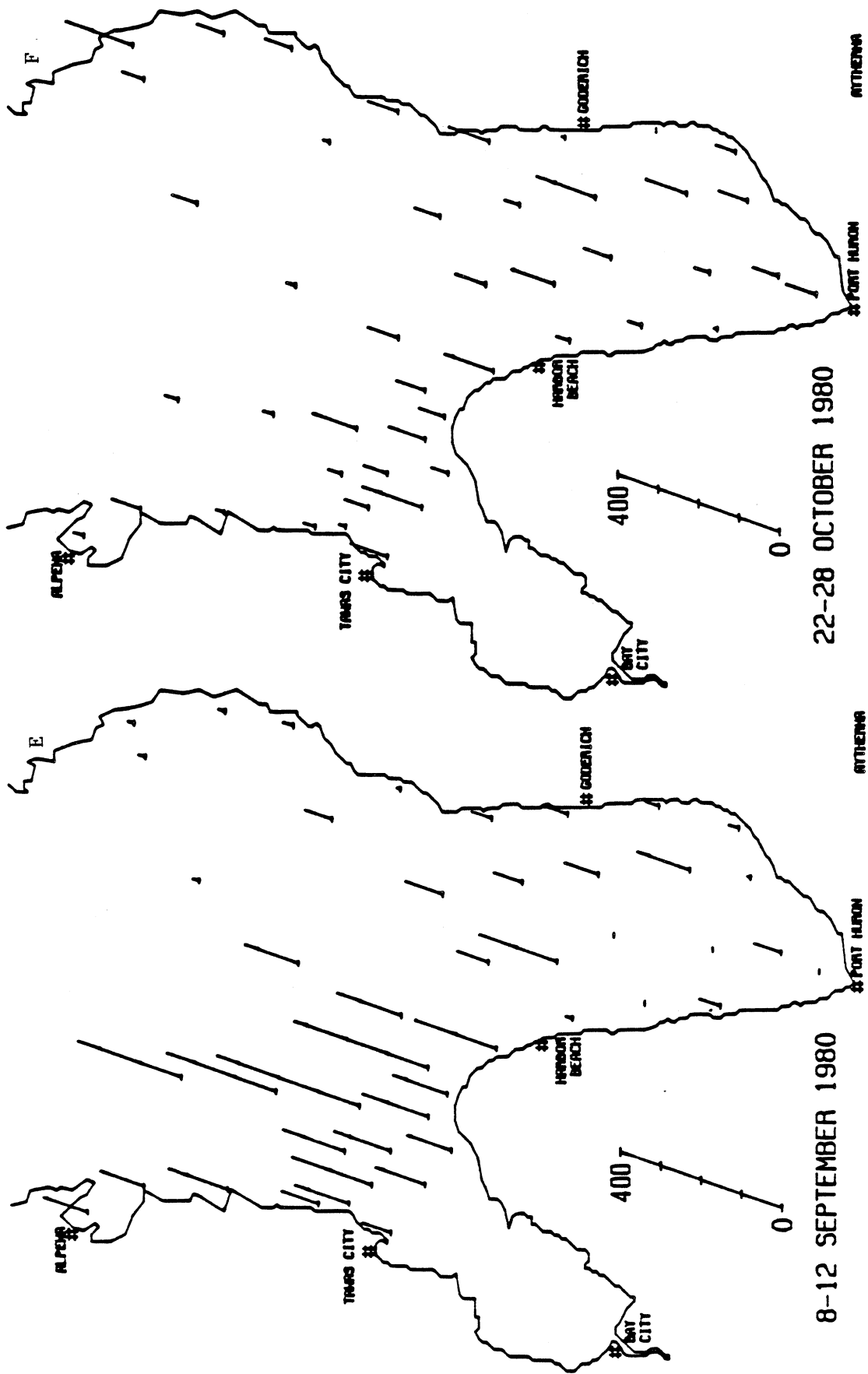


FIG. 44. (continued)

blooms (Drouet and Daily 1956). Colonies of G. lacustris generally contain 75-500 individuals which are most densely packed toward the matrix periphery. In this study, on average, it was the second most abundant blue-green alga. During April (Fig. 45A), occurrences at low abundance were recorded near Saginaw Bay and the southern basin. Very low abundance was observed from May through July (Figs. 45B-45D). Increased abundance was recorded in September (Fig. 45E), reaching highest abundance in Thunder Bay and extending southward. Most occurrences were in the central basin and the Saginaw Bay interface zone. Distinctly fewer occurrences were observed in the southern basin and the eastern portion of the central basin. On average, greatest abundance and occurrence was observed in October (Fig. 45F). High cell concentrations were seen in the waters adjacent to Saginaw Bay and in the mid-southern basin. Fewer occurrences and comparatively less abundances were again observed in the eastern sector of the study area.

#### Oscillatoria bornetii--

This taxon is a filamentous blue-green alga usually found in low abundance in the plankton of the upper Great Lakes. Its autecology and distribution are very poorly known. It has, however, been reported to have a wide range of tolerance from alpine lakes (Huber-Pestalozzi 1938) to meso-eutrophic waters (VanLandingham 1982). In April (Fig. 46A), it was well distributed over the study area, with greatest abundances north of Saginaw Bay. One large population was observed in the upper sector of the southern basin. During May (Fig. 46B), greatest abundance again occurred north of Saginaw Bay as well as south of Goderich in the southern basin. A sporadic distribution was seen in June (Fig. 46C). High abundances were observed in

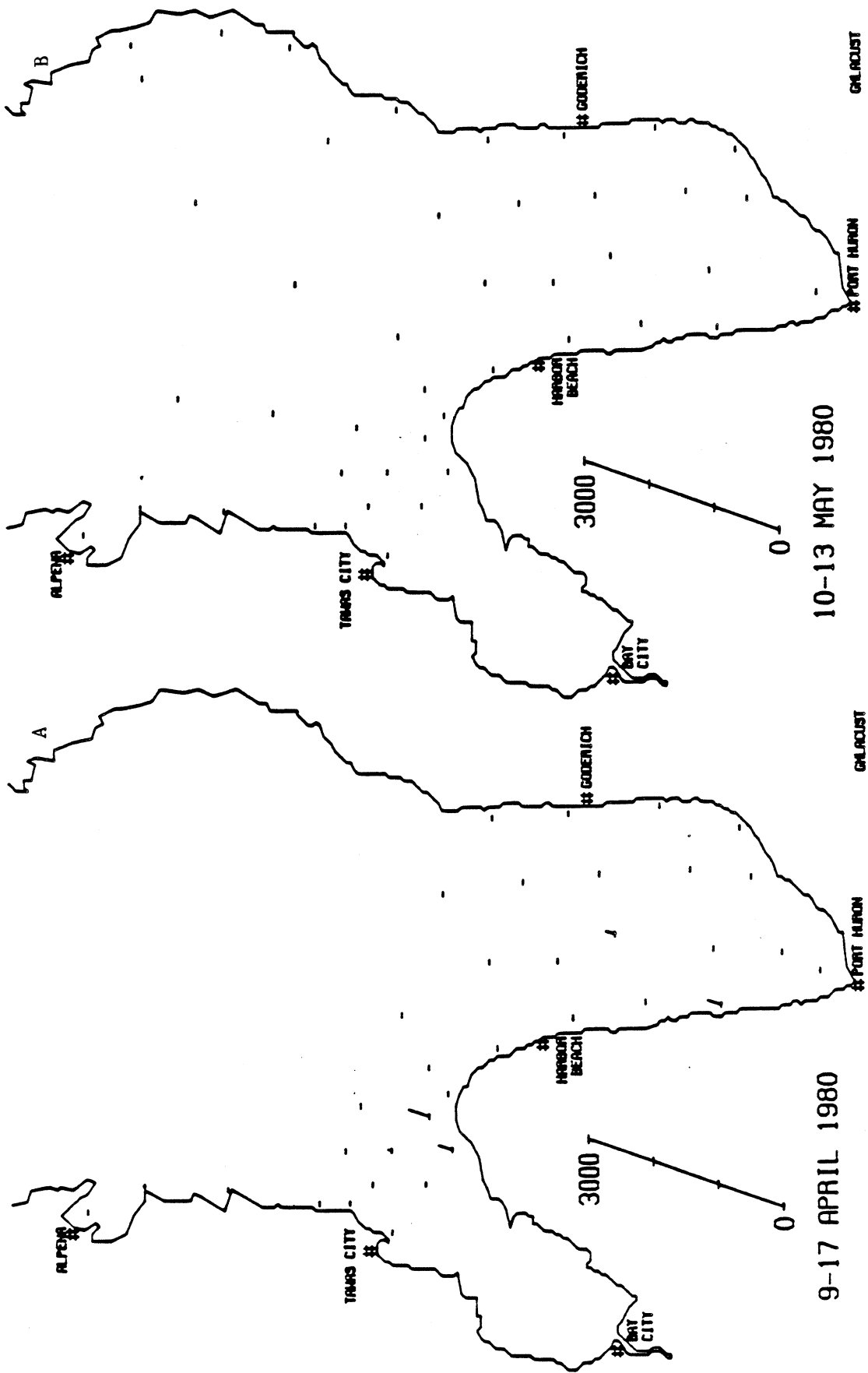


FIG. 45. Distribution of *Gomphosphaeria lacustris*.

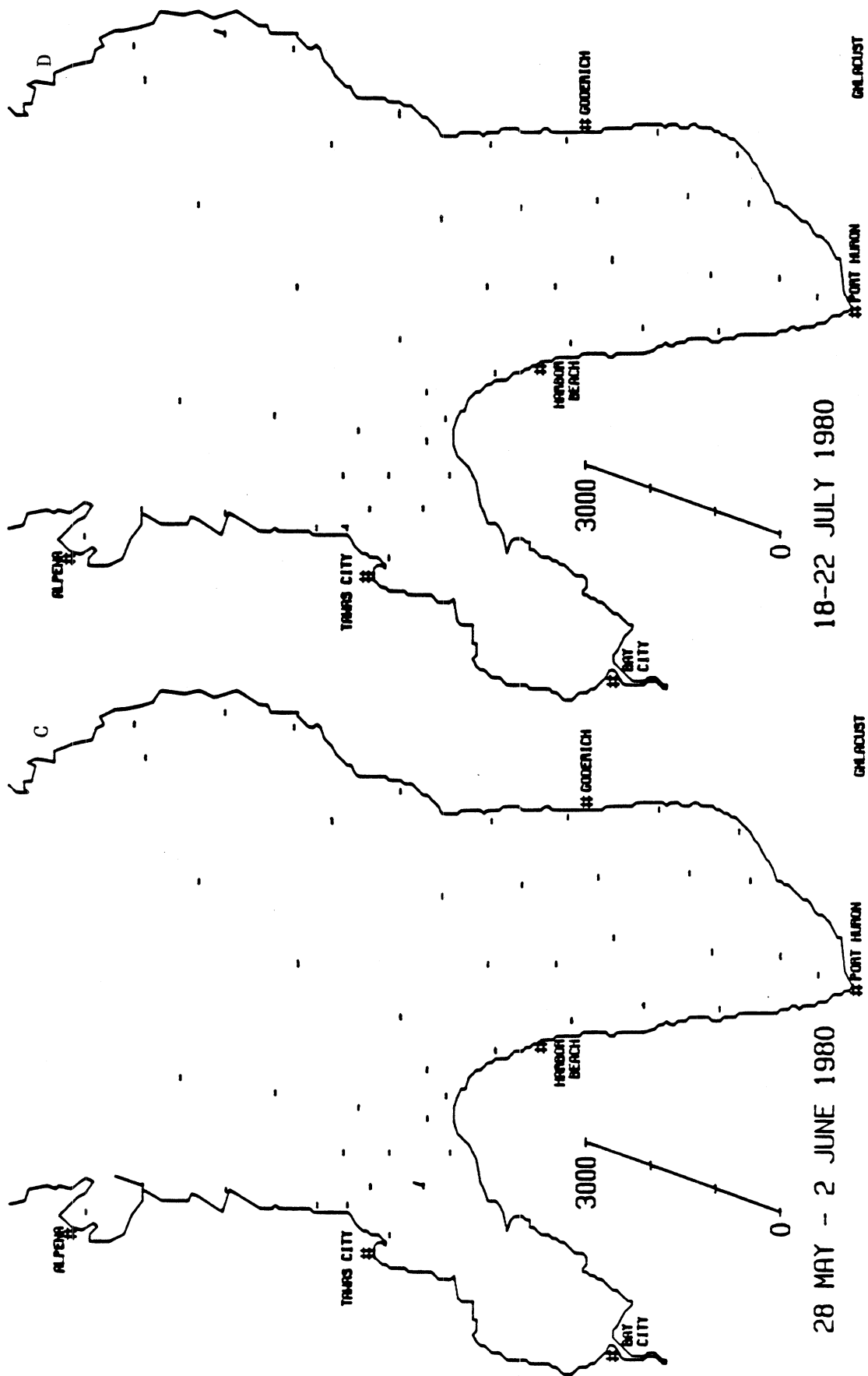


FIG. 45. (continued)

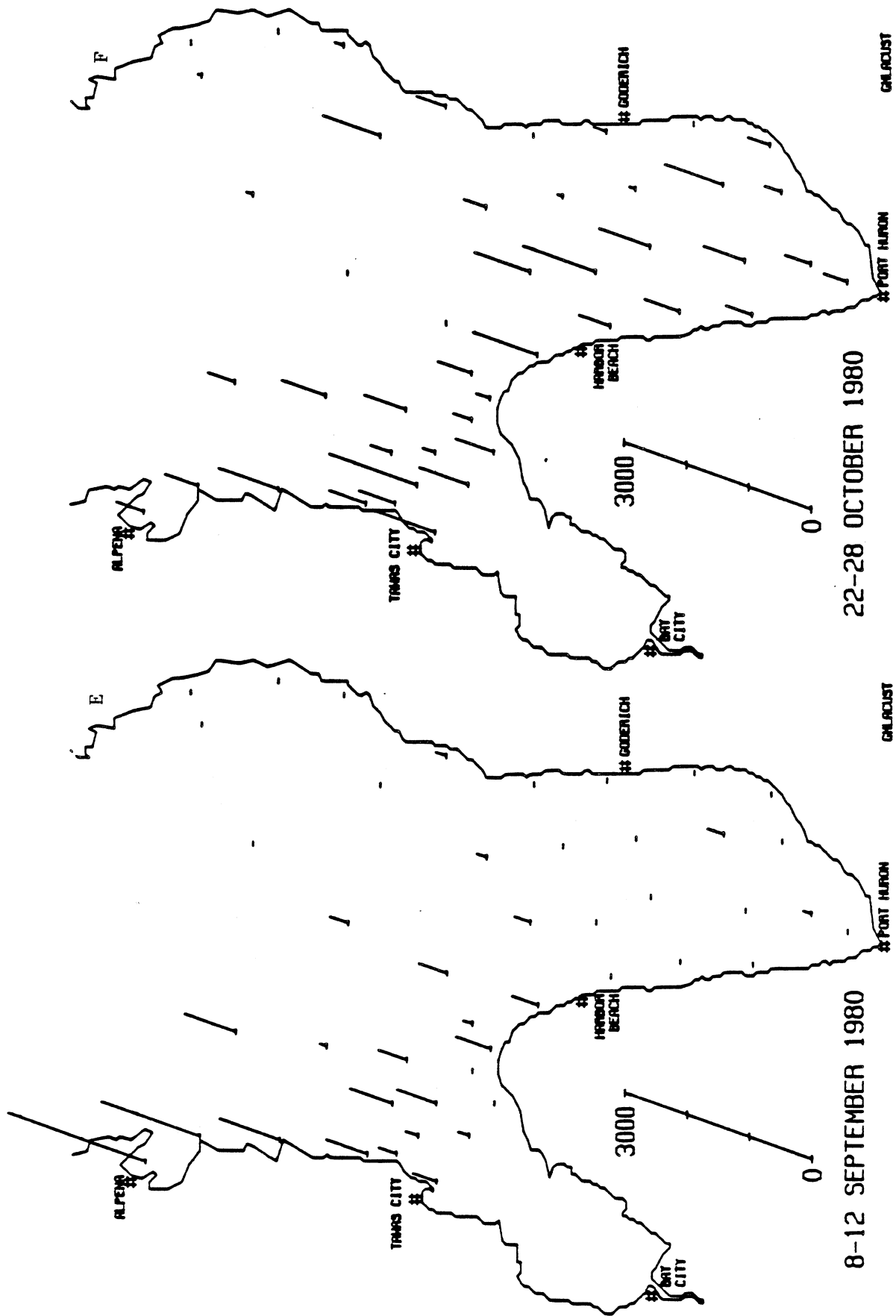


FIG. 45. (continued)

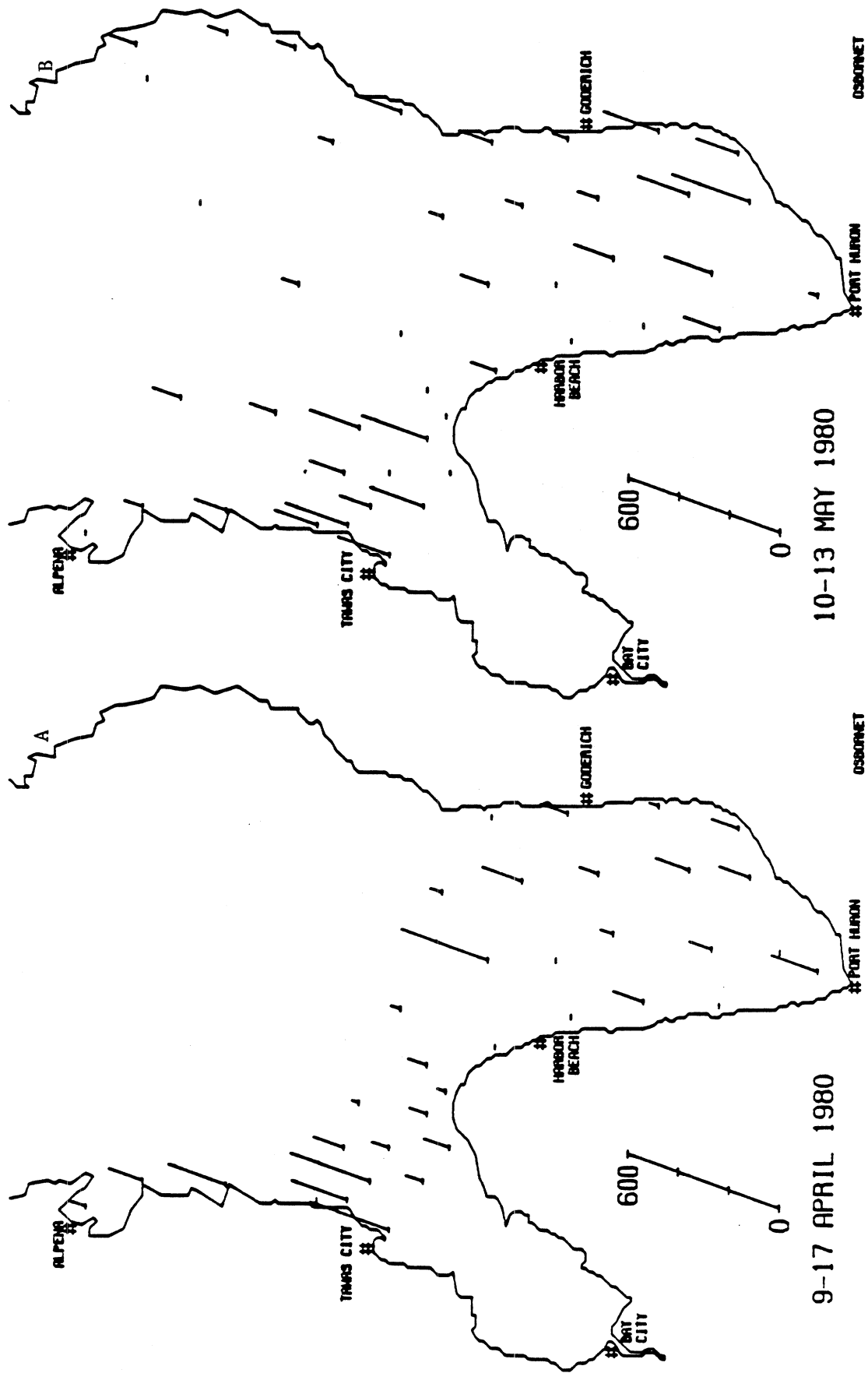


FIG. 46. Distribution of Oscillatoria bornetii.

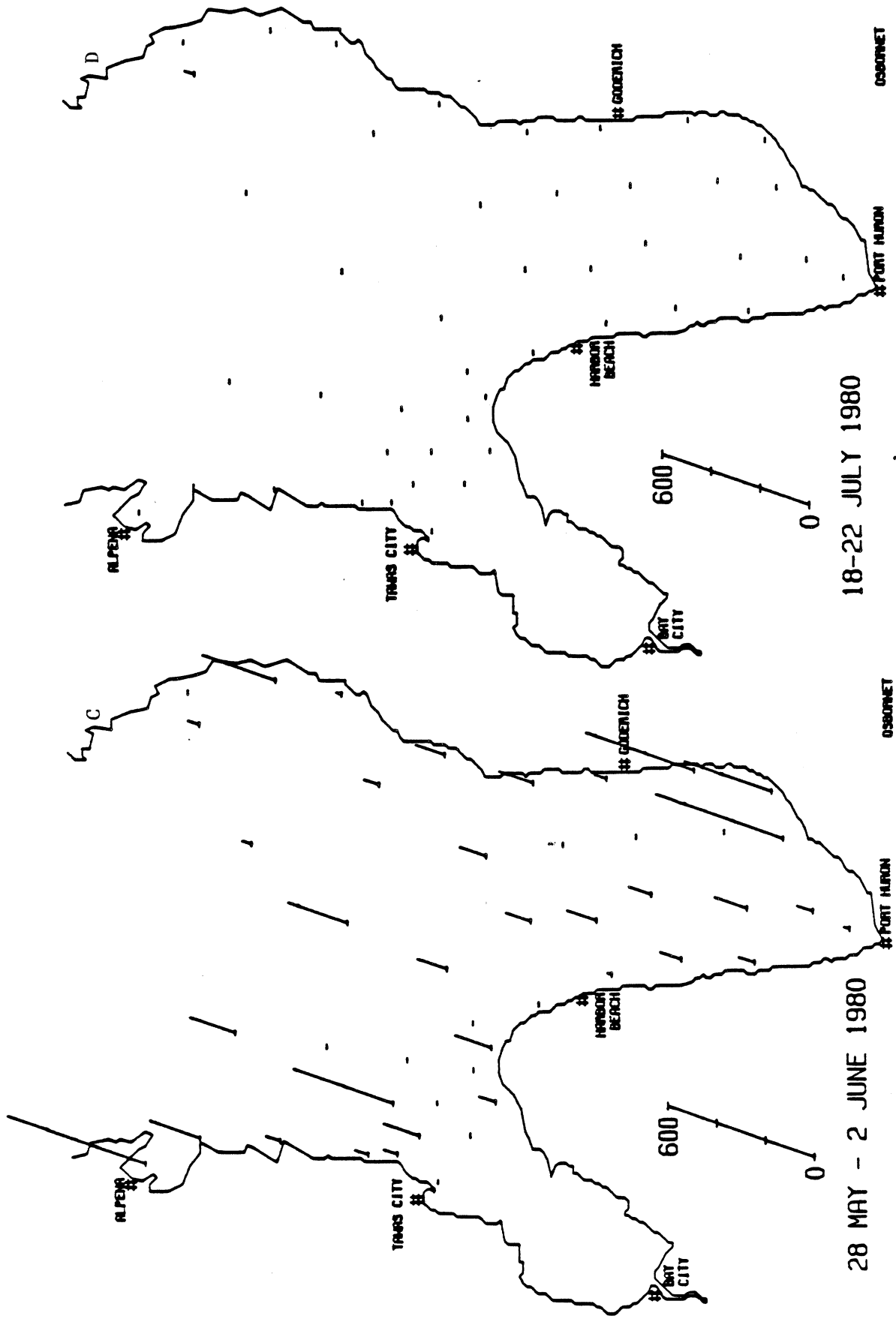


FIG. 46. (continued)

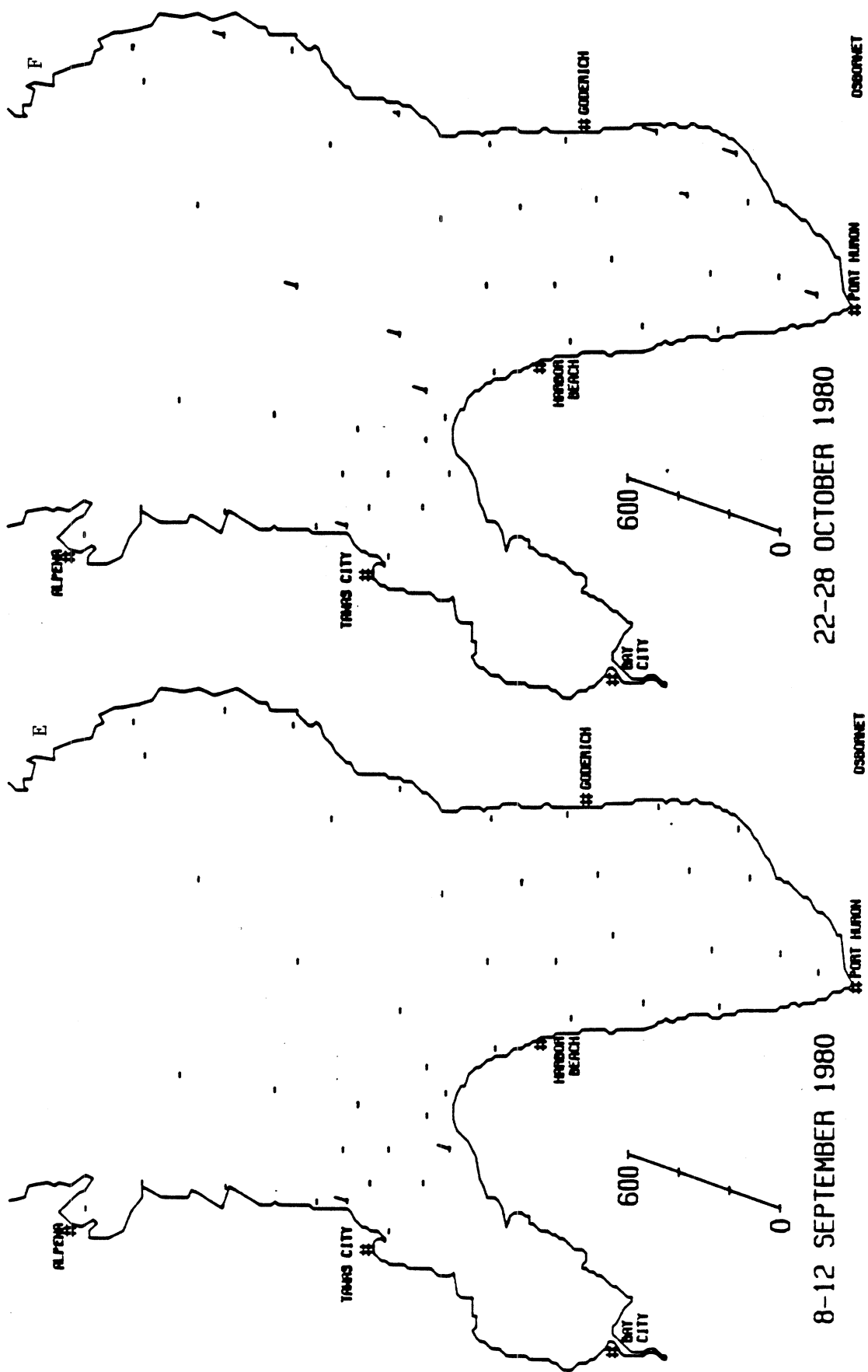


FIG. 46. (continued)

Thunder Bay, in the western portion of the central basin, and near Goderich. Reduced abundances were observed from July through October (Figs. 46D-46F).

#### Schizothrix calcicola---

Very little is known about the distribution and ecology of this small filamentous blue-green in the Great Lakes. It has seldom been reported from the Great Lakes in appreciable quantities. It is included here due to its odd distribution patterns. In April (Fig. 47A), it occurred in the Saginaw Bay interface and southern basin. Its greatest abundance was in the southern coastal zone. During May (Fig. 47B), its occurrence was centered on the eastern side of the study area both nearshore and offshore. In June (Fig. 47C), it had its greatest abundance in the central basin, with a few occurrences in the upper southern basin. Highest abundances were recorded for the Canadian nearshore zone in the central basin. From July through October (Figs. 47D-47F), sporadic occurrences at low abundance were observed.

#### Total Flagellates

This category is a composite of all microflagellates comprised of all flagellate groups from the Chrysophyta, Cryptophyta, Pyrrophyta, Euglenophyta, and the undetermined category. Collectively, they constitute a considerable portion of southern Lake Huron phytoplankton assemblages. They were most abundant during the spring sampling periods. During April (Fig. 48A), flagellates reached their highest average abundance for the season. Abundances were highest in Thunder Bay and in the nearshore zone southward to Tawas City. Abundances were also high in the northern portion of the Saginaw Bay interface. Lower, uniform abundance was observed in the southern basin. During May (Fig. 48B), on average, slightly reduced

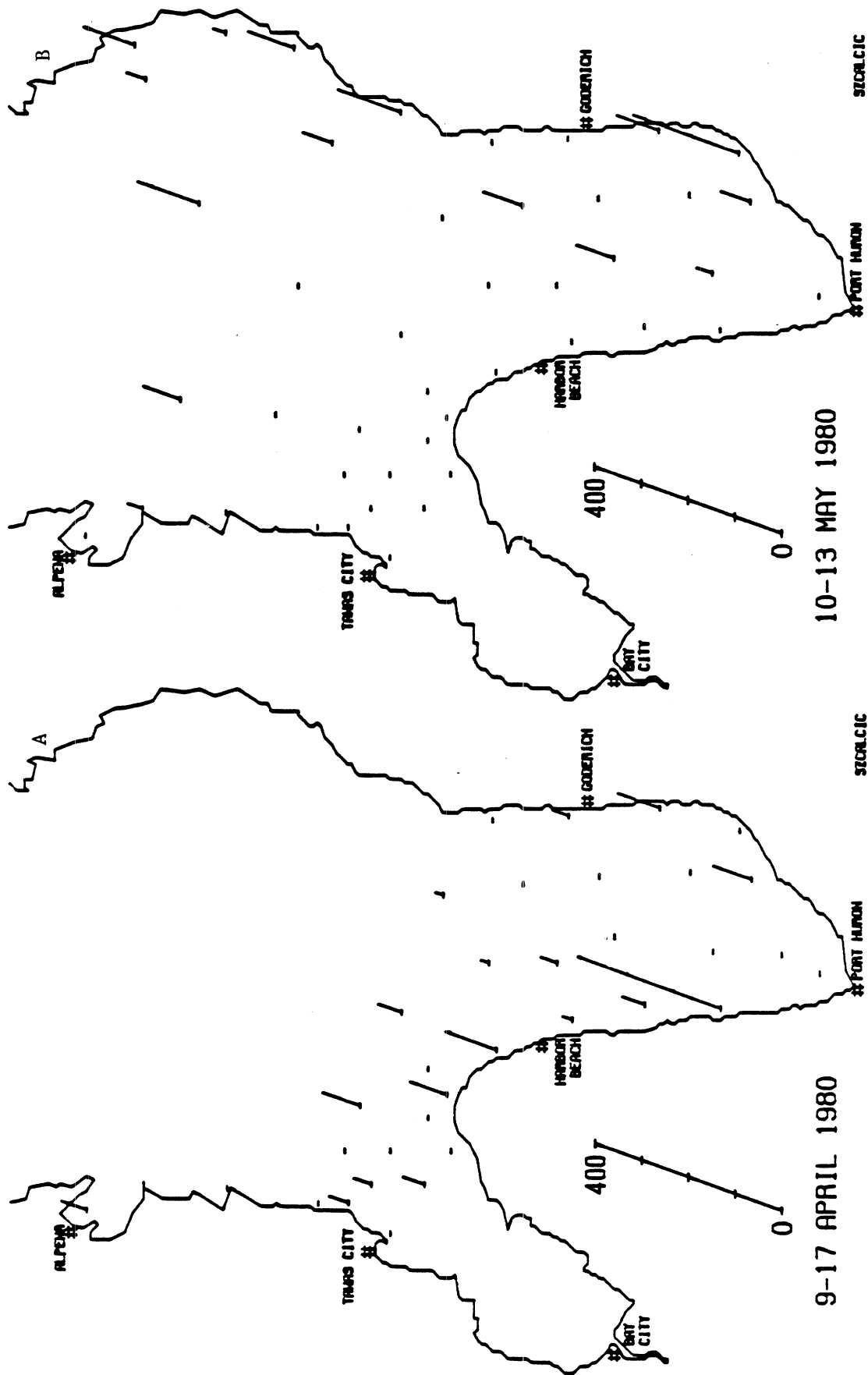


FIG. 47. Distribution of *Schizothrix callicola*.

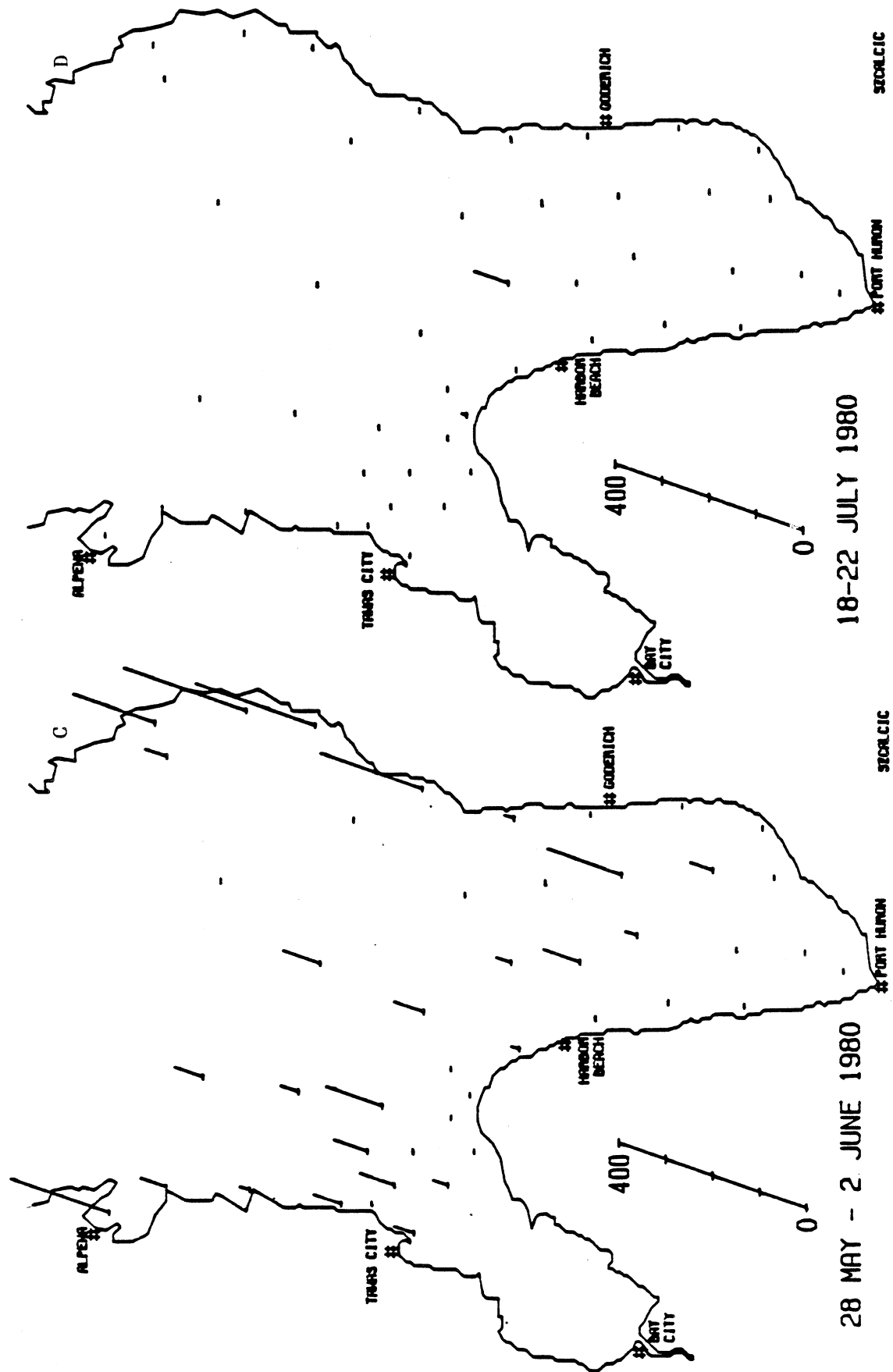


FIG. 47. (continued)



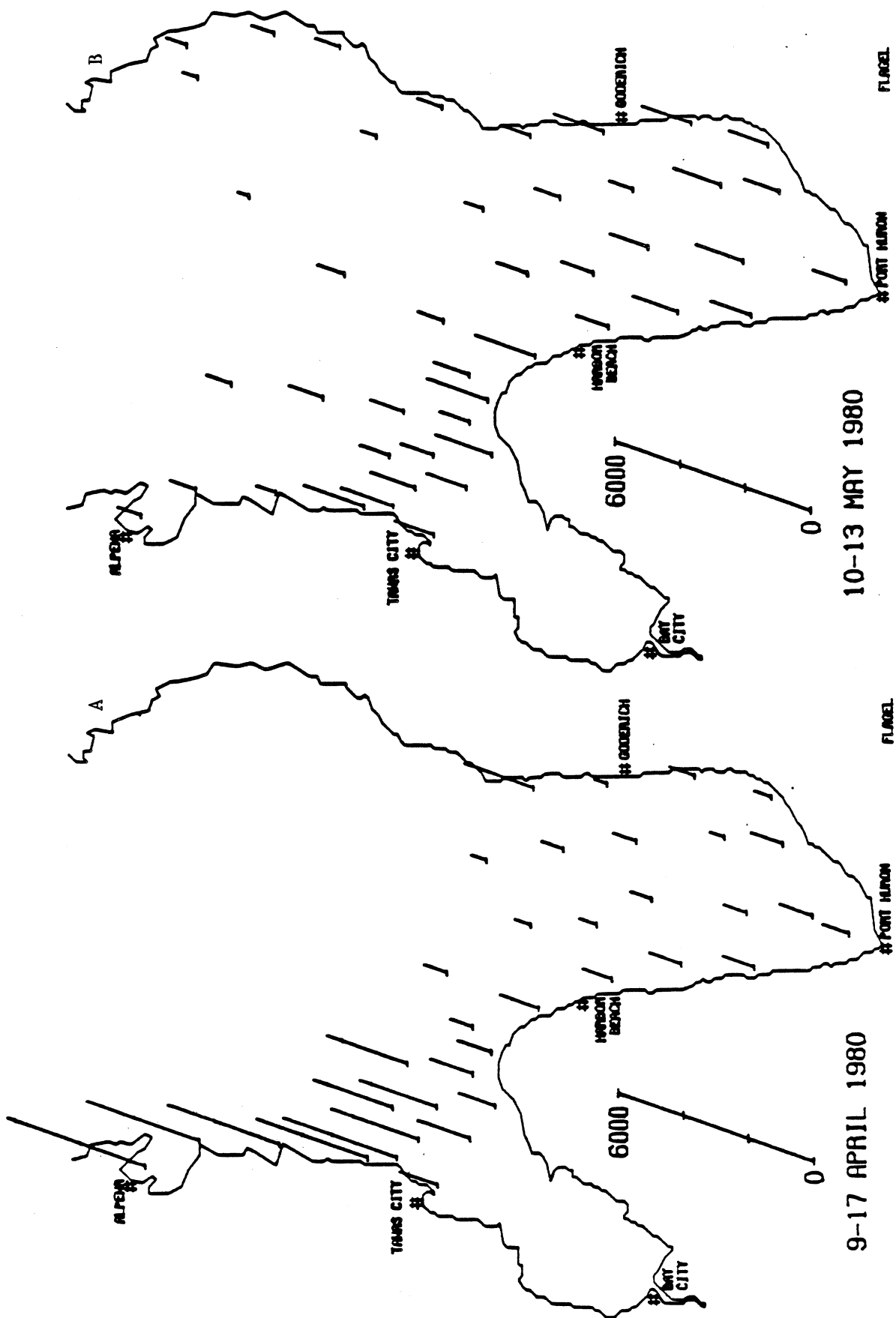


FIG. 48. Seasonal distribution and abundance trends (cells/mL) of total flagellates, 1980.

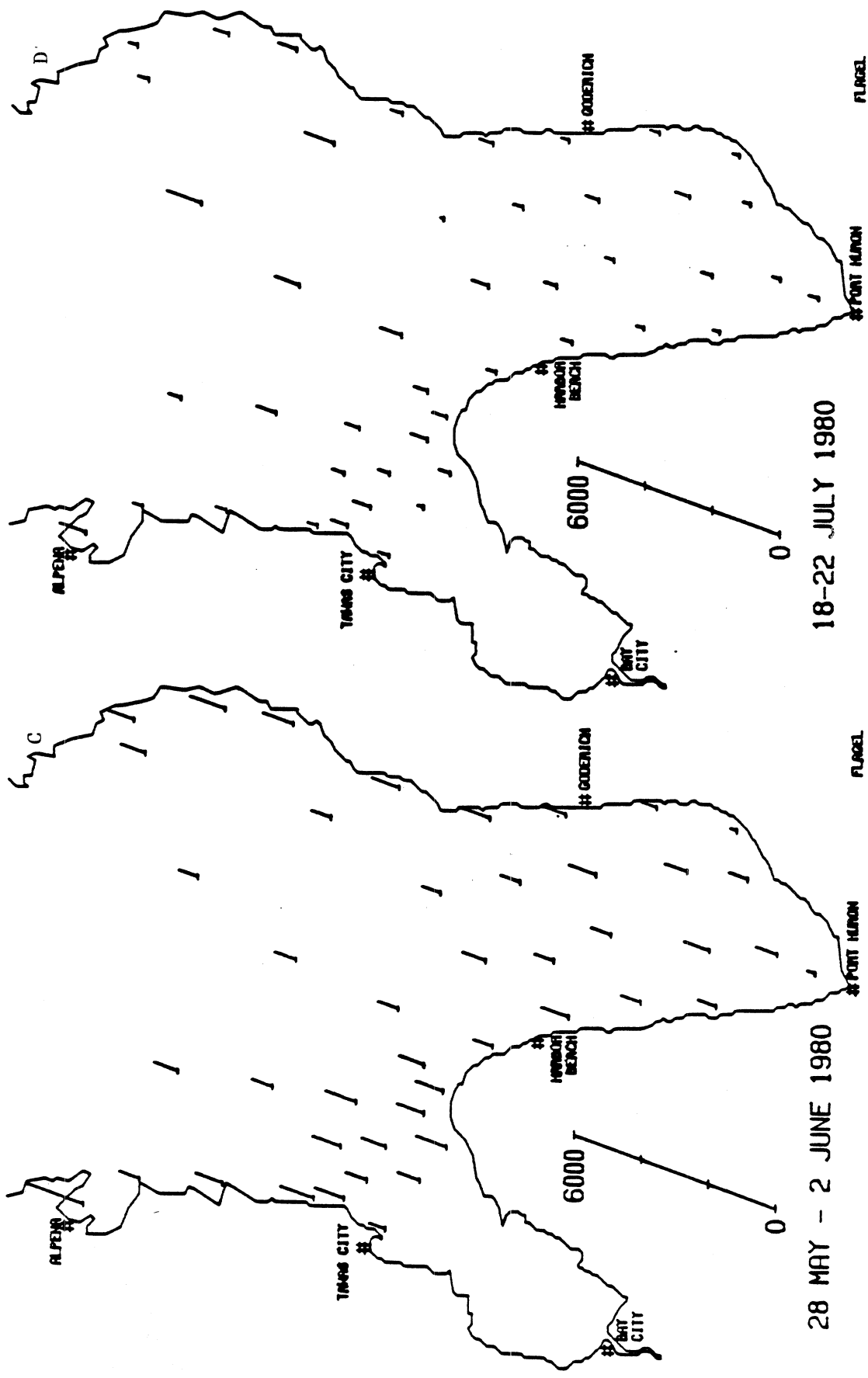


FIG. 48. (continued)

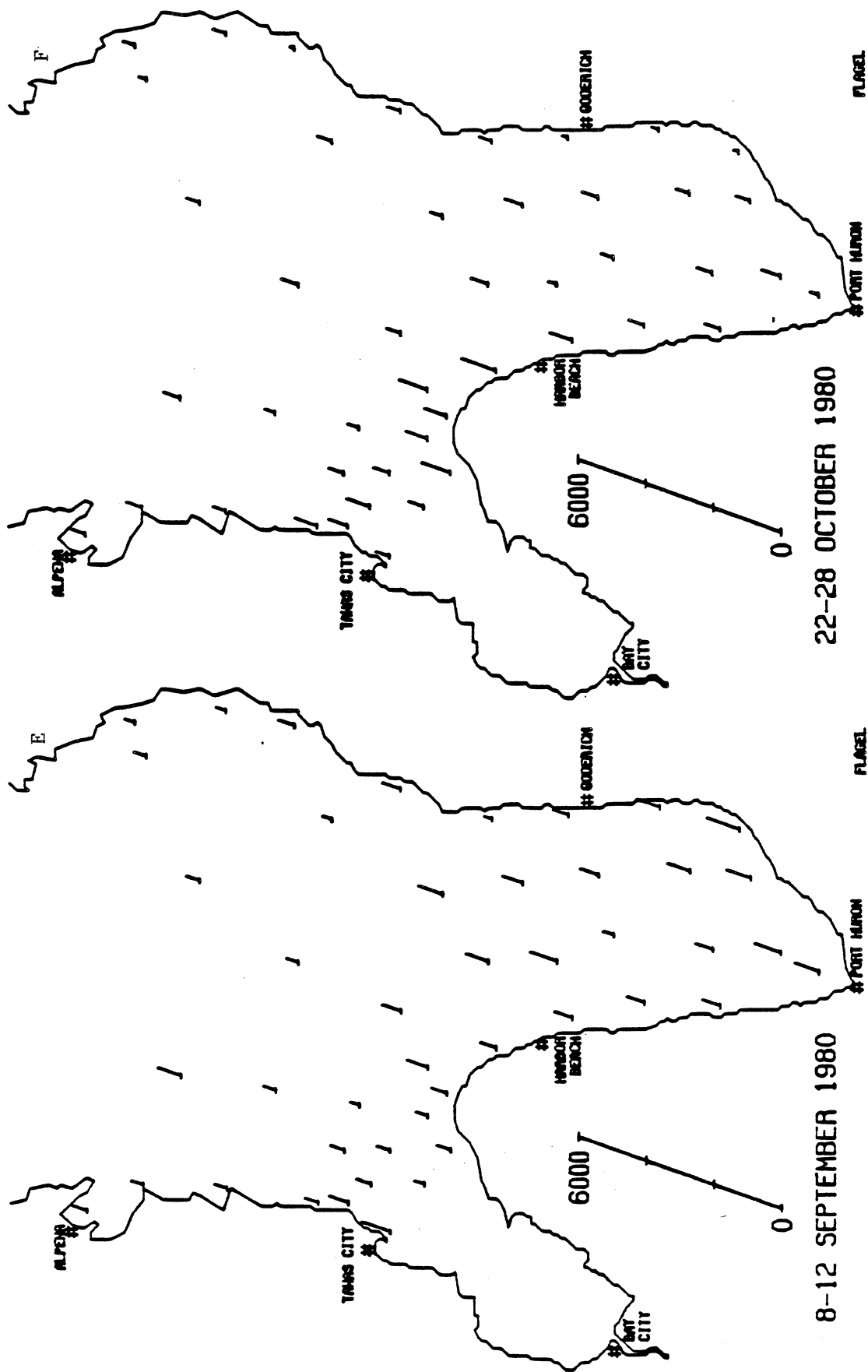


FIG. 48. (continued)

abundances were observed. Highest abundances were recorded in the Saginaw Bay interface. Compared to April, slightly increased cell numbers were observed in the southern basin. Decreased abundance was observed in the nearshore zone between Alpena and Tawas City. Remarkably uniform, moderate abundances were recorded in June (Fig. 48C). During July (Fig. 48D), abundances decreased, especially in outer Saginaw Bay and the southern basin. Highest cell numbers were reported for the mid-central basin during this month. During September and October (Figs. 48E and 48F), rather uniform distributions and abundances were observed.

#### Undetermined Microflagellates--

The abundances and distribution patterns reported for total flagellates were also observed for the undetermined flagellate category (Figs. 49A-49F). Considering the large proportion of undetermined microflagellates in the total flagellate values, the similarity is reasonably expected. This category is comprised of small forms possibly aligned with little-known groups such as the haptophytes, chloromonads and chrysophytes as previously mentioned.

#### Flagellate sp. #15--

This flagellate form could not be aligned with a known taxonomic entity and has not been previously observed in the Great Lakes. It is very small, approximately 4  $\mu\text{m}$  in diameter, exhibiting an oval cell shape. There is a possibility that it also occurs in a colonial habit. Although it is not assigned to a specific taxon it could be separated by its morphological characters. It reached its greatest abundance for the season in April (Fig. 50A) in the nearshore area between Alpena and Tawas City. These abundances accounted for the large values observed in the total flagellate

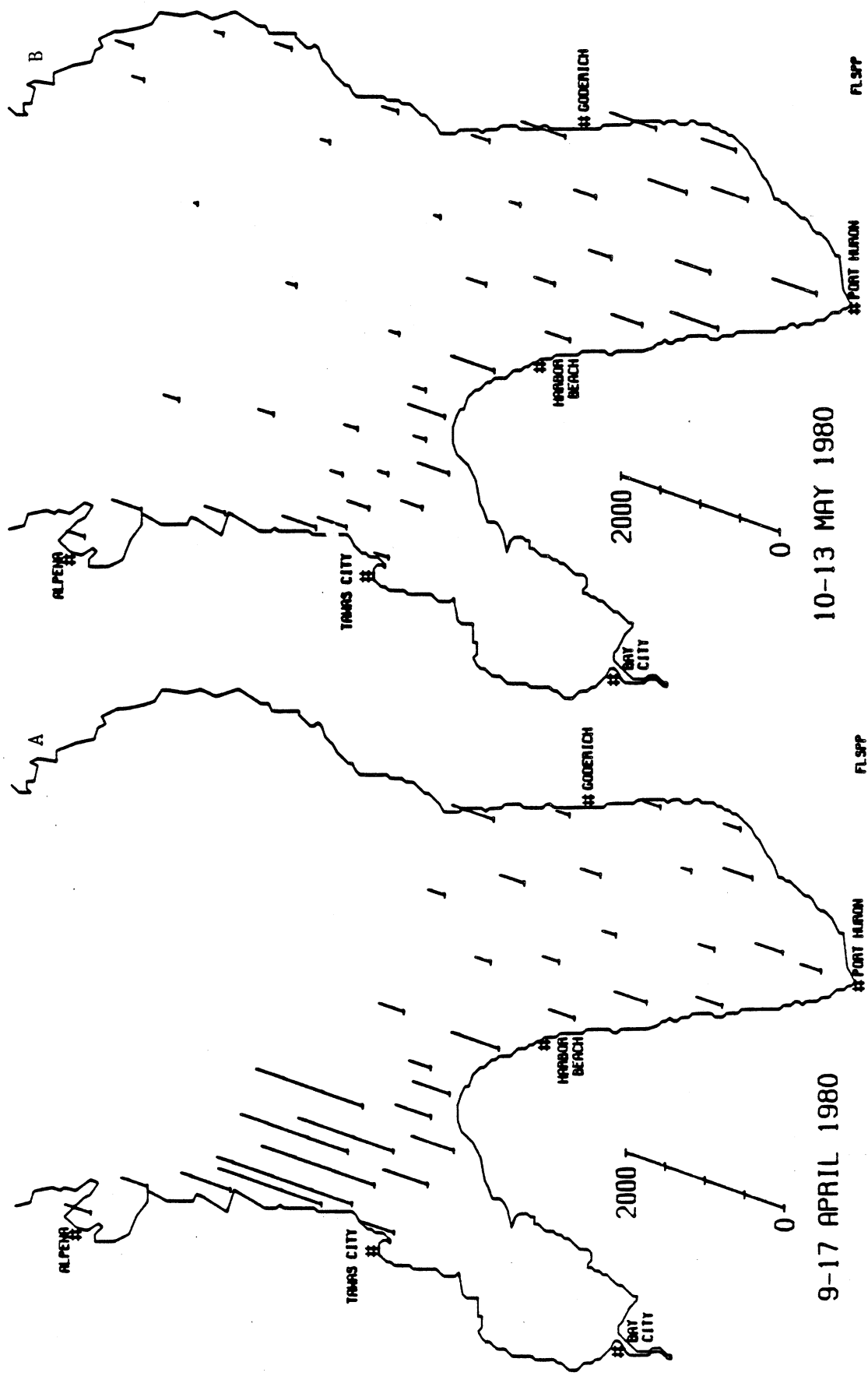


FIG. 49. Distribution of undetermined microflagellates.

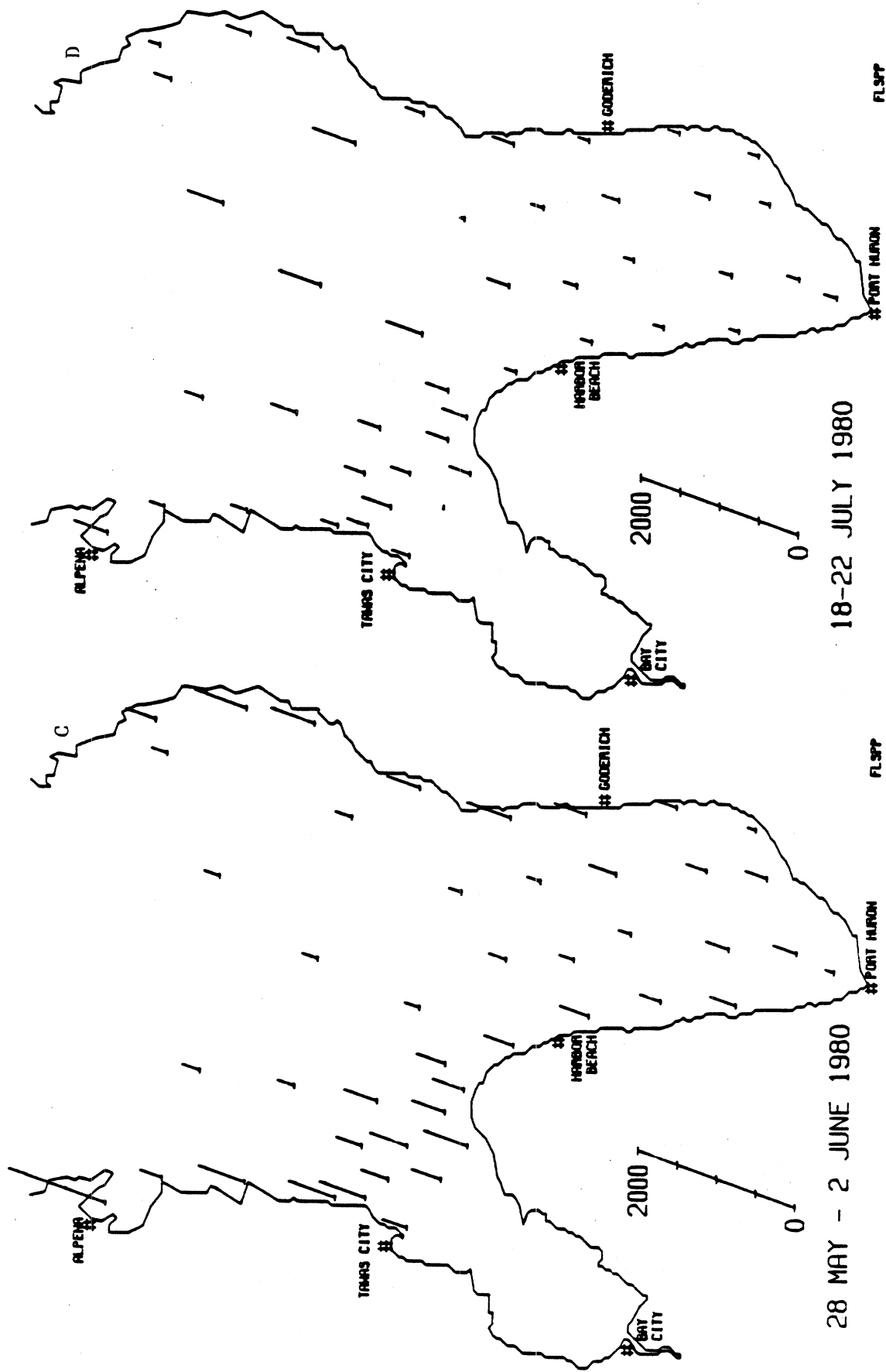


FIG. 49. (continued)

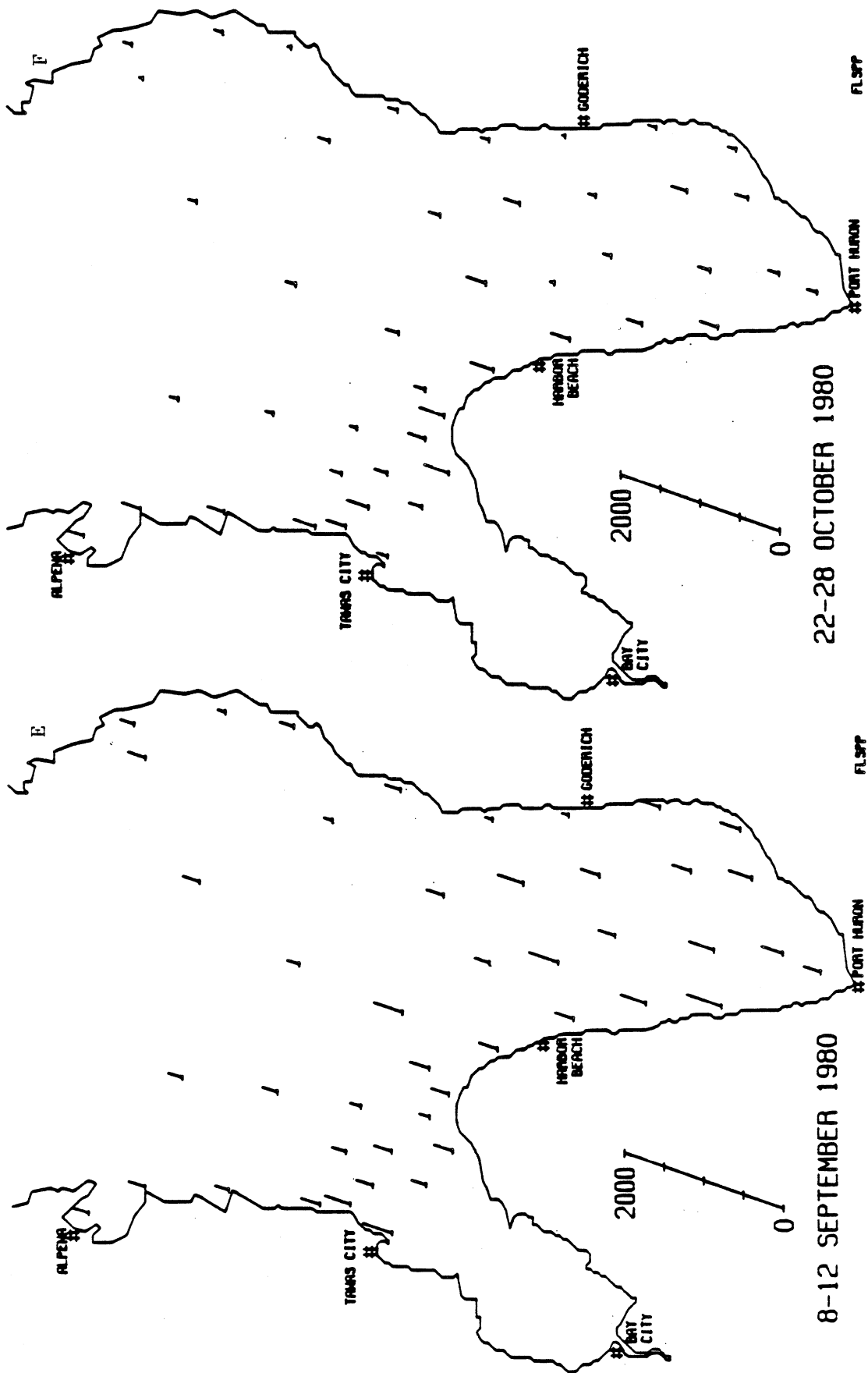


FIG. 49. (continued)

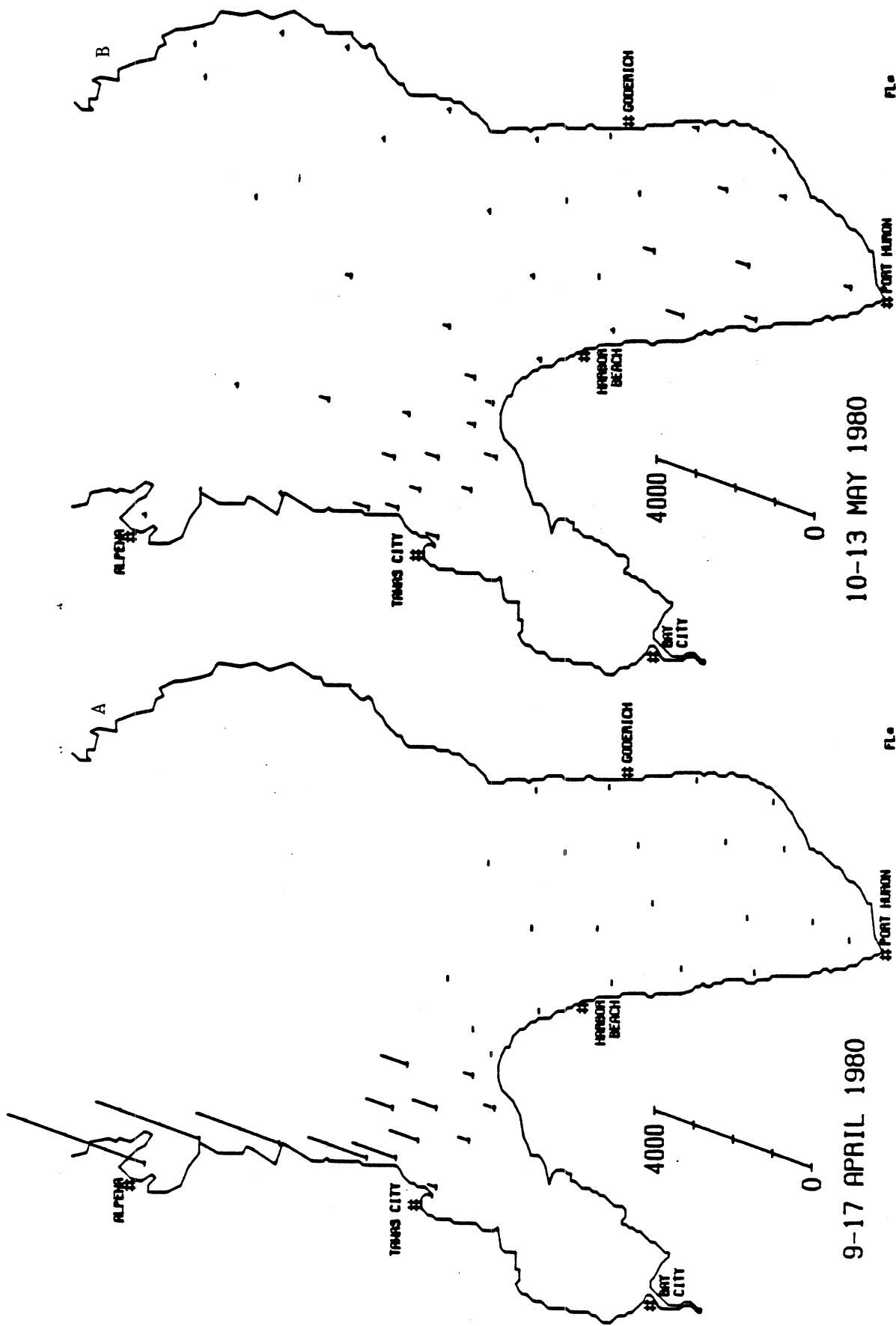


FIG. 50. Distribution of flagellate sp. #15.

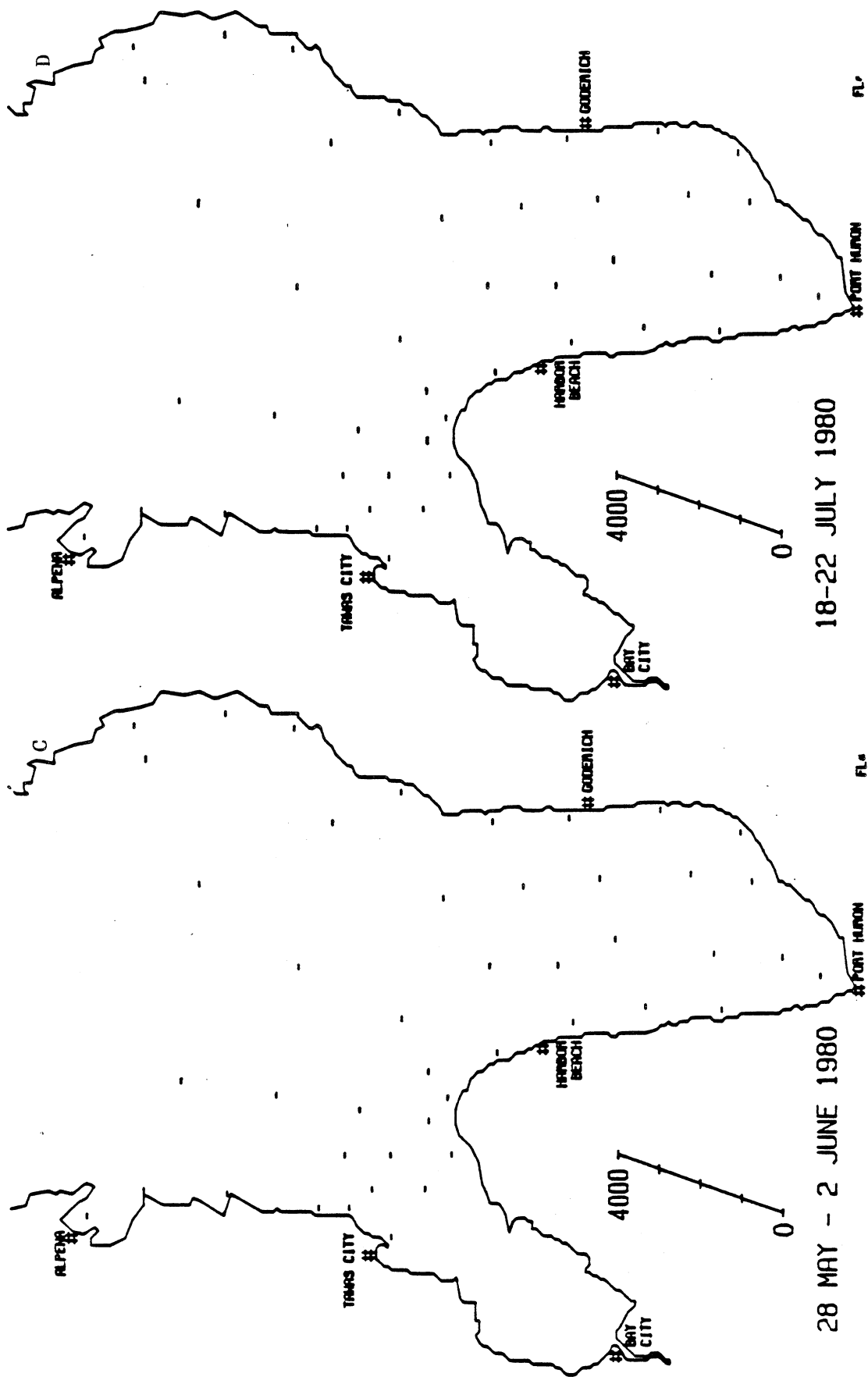


FIG. 50. (continued)

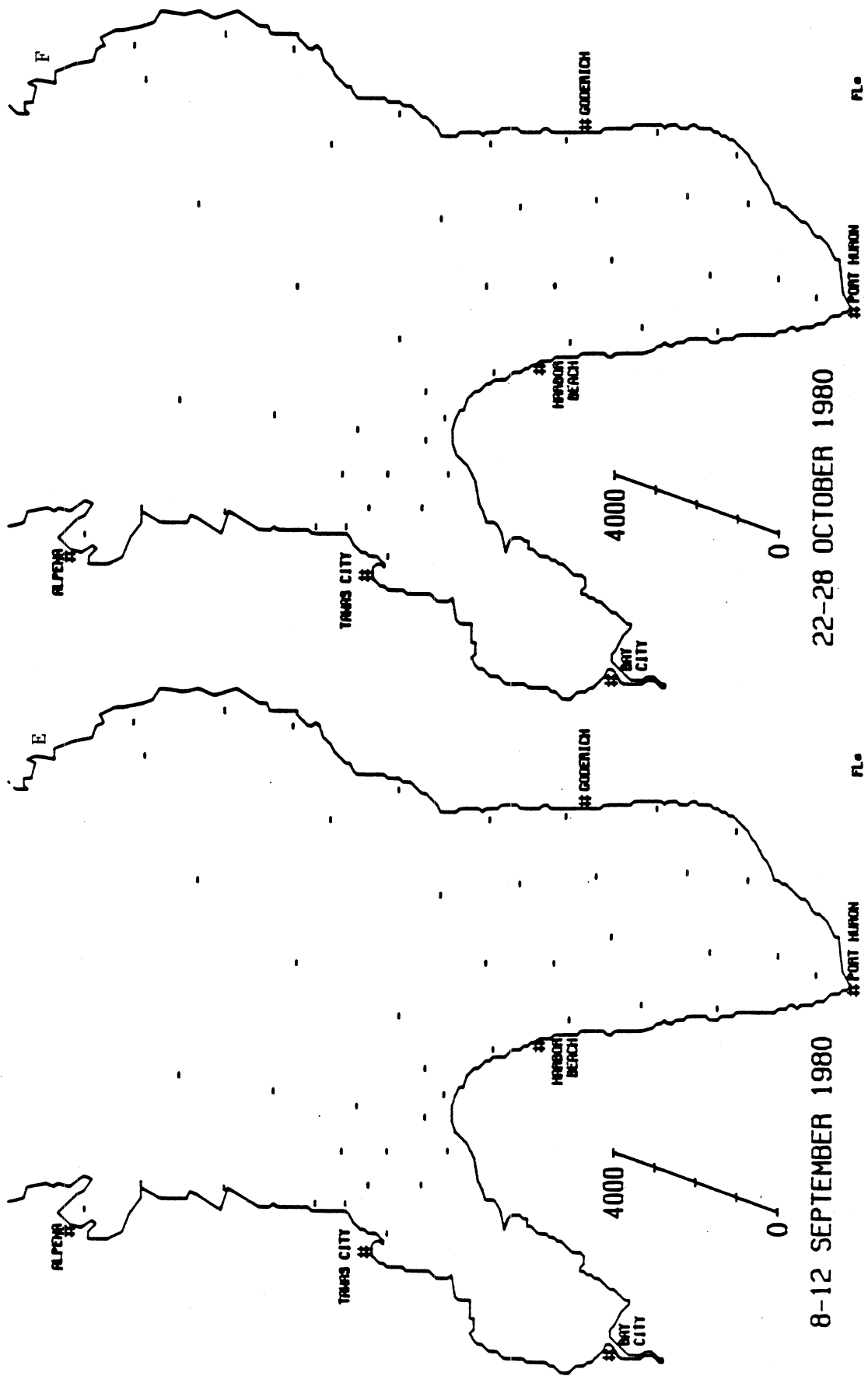


FIG. 50. (continued)

category at this location. It was also moderately abundant in outer Saginaw Bay and slightly higher in the interface zone. During May (Fig. 50B), it reached its widest distribution with greatest abundance in outer Saginaw Bay, the interface area, and the lower southern basin. For the remainder of the year (Figs. 50C-50F), extremely low cell concentrations were recorded.

#### Chrysophyta - Chrysophytes

The chrysophytes have long been recognized as an important component of the algal flora of the upper Great Lakes. The Laurentian Great Lakes have been referred to as "diatom and chrysophyte lakes" in reference to their dominance in net plankton tows taken in the early stages of phytoplankton research. Various chrysophytes have been associated with oligotrophy but occur in the entire trophic spectrum (Hutchinson 1967). The majority of chrysophytes observed in southern Lake Huron are flagellated colonial forms. During April and May, they reached their greatest seasonal abundance and occurrence in southern Lake Huron. In April (Fig. 51A), chrysophytes were present in moderate concentrations over the survey area. Greatest abundance was seen at one nearshore station north of Goderich. High values were also reported near Alpena and in Saginaw Bay. During May (Fig. 51B), cell numbers increased to their greatest abundance for the season. Highest values were observed in the waters adjacent to Saginaw Bay with lower values observed in the central basin. Reduced abundance was observed in June (Fig. 51C) showing a uniform distribution. Lowest abundances for the season were seen in July (Fig. 51D) although chrysophytes were present at most stations. Greatest standing crops were observed in the Saginaw Bay interface waters and the central basin. Increased abundance was observed in September (Fig. 51E) with

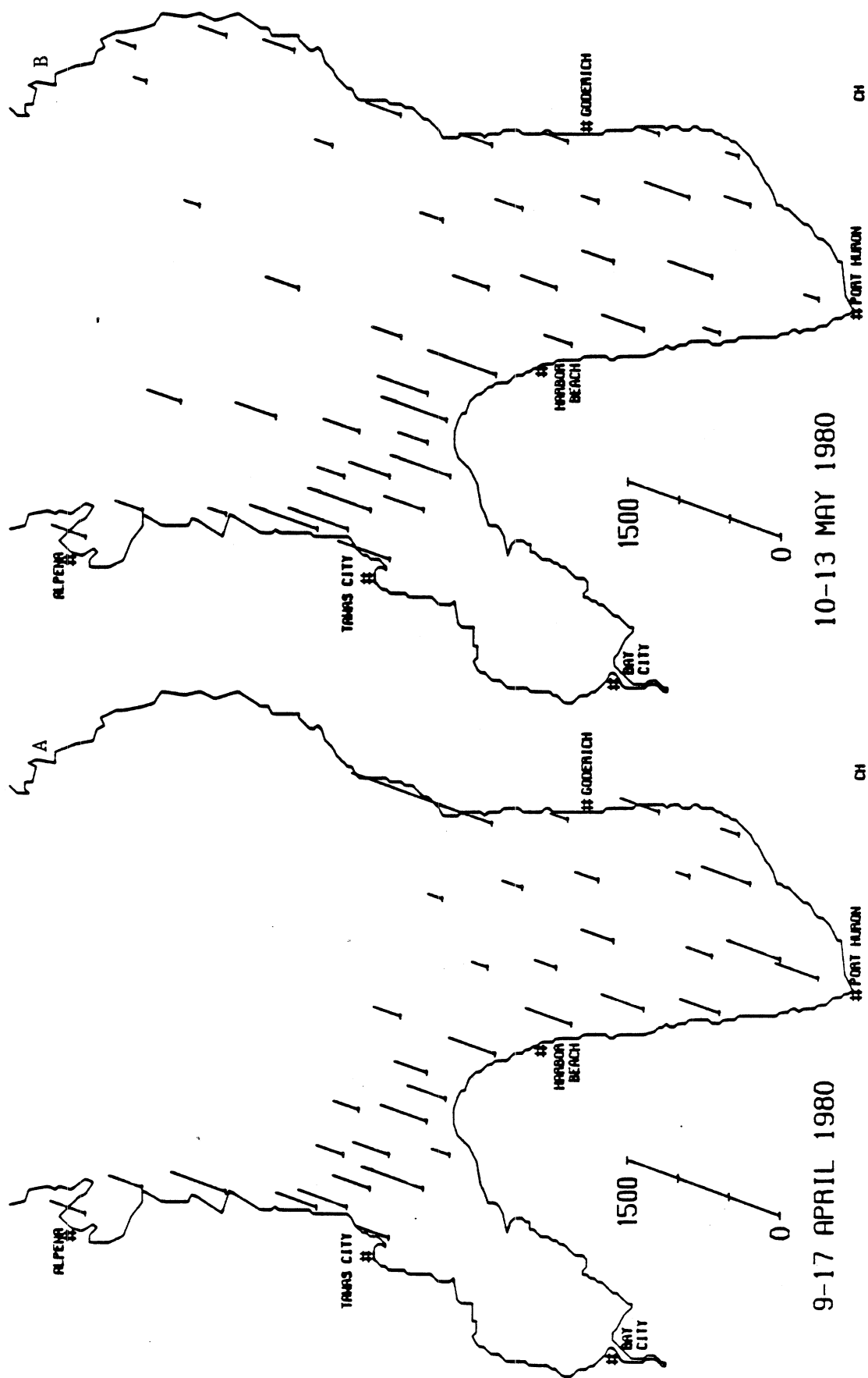


FIG. 51. Seasonal distribution and abundance trends (cells/mL) of chrysophytes, 1980.

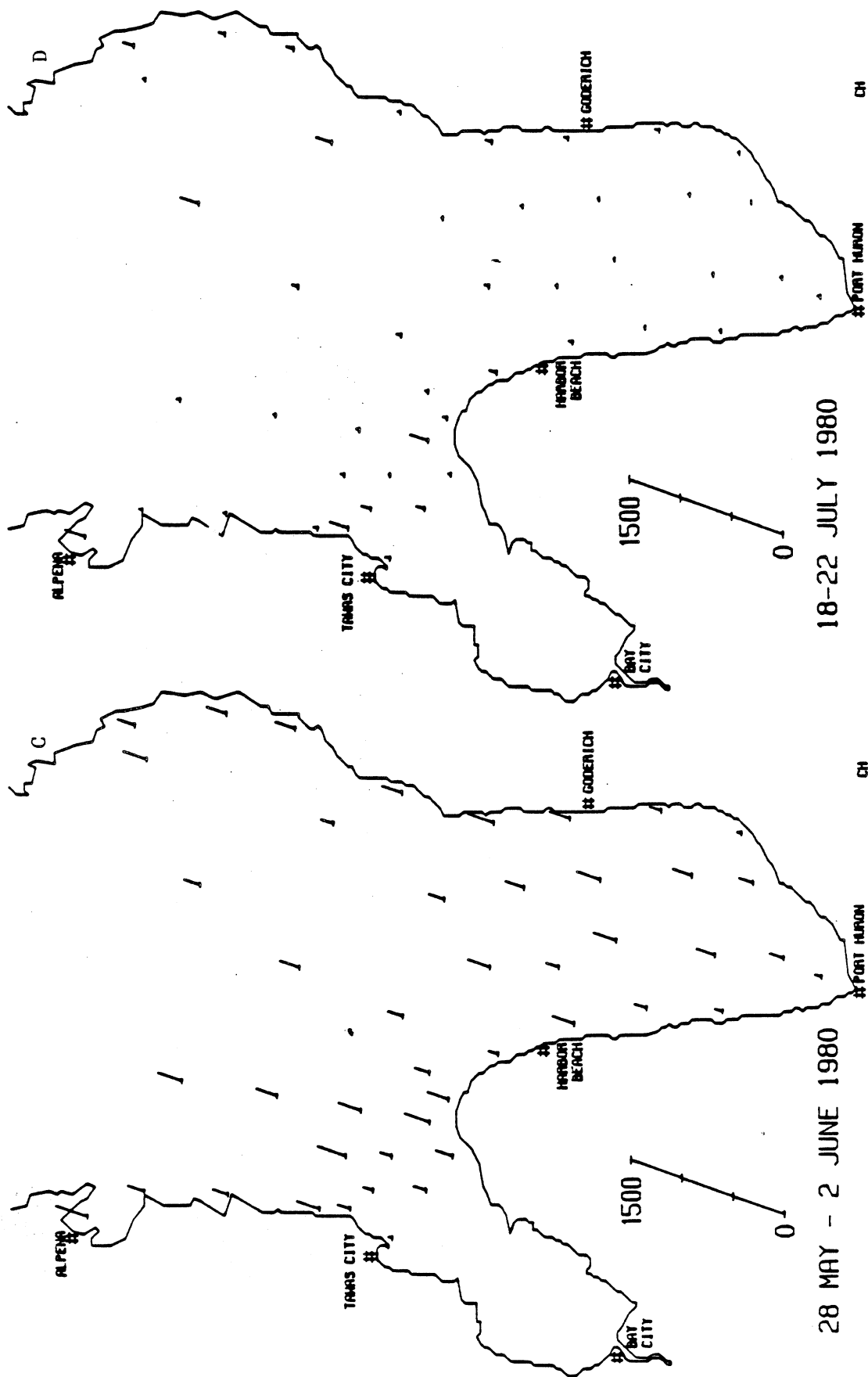


FIG. 51. (continued)

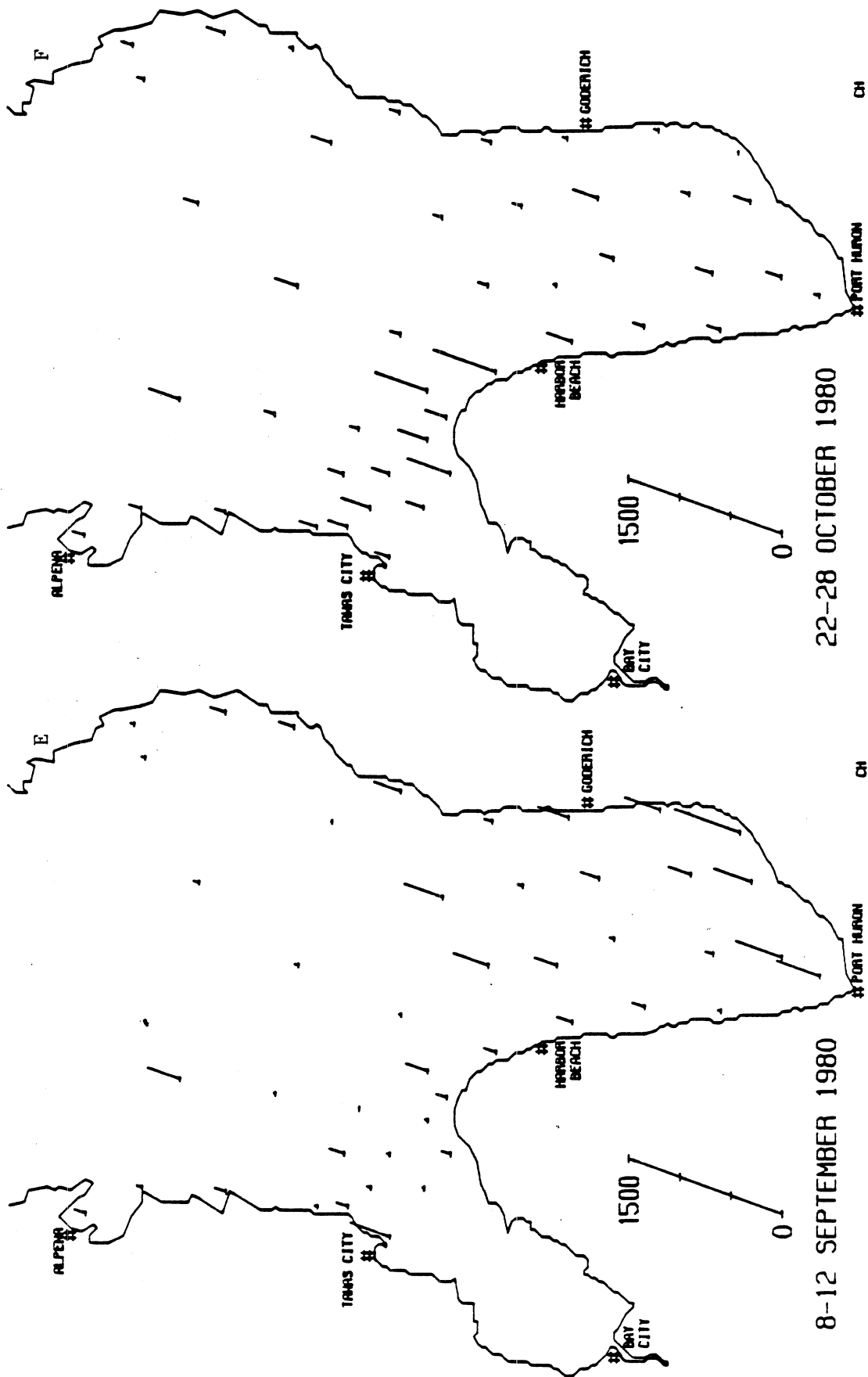


FIG. 51. (continued)

highest concentrations in the lower portion of the southern basin. Elevated abundances were recorded for October (Fig. 51F) with greatest abundances in the Saginaw Bay interface.

Chrysococcus dokidophorus--

Very little is known about the autecology and distribution of this small, flagellate species. In April (Fig. 52A), it was widely distributed in low abundances in the southern basin. Reduced densities were observed in May (Fig. 52B), revealing no apparent distributional pattern. Similarly, in June (Fig. 52C), low abundances were recorded showing no distinct pattern. Elevated cell numbers, especially in the nearshore areas around the lake were observed in July (Fig. 52D). It also showed a wide distribution over the entire study area. Few occurrences and decreased abundance were observed in September (Fig. 52E). Populations were concentrated in the central basin and the adjacent waters of Saginaw Bay. Increased abundance and occurrence were recorded in October (Fig. 52F), reaching this species' greatest average abundance for the year. It was widespread throughout the study area with largest abundances in the southern basin and generally in offshore waters.

Chrysosphaerella longispina--

Populations of this species were only recently recorded from the Great Lakes and are apparently most abundant in Lake Huron (Stoermer et al. 1976, Lowe 1976, Stoermer and Kreis 1980). It is a relatively large, motile colony containing up to 640 individuals per colony. This species was not observed in southern Lake Huron until July (Fig. 53A), when an isolated population was recorded in the northern Saginaw Bay interface. It reached its greatest abundance and occurrence in September (Fig. 53B). It was most abundant in the

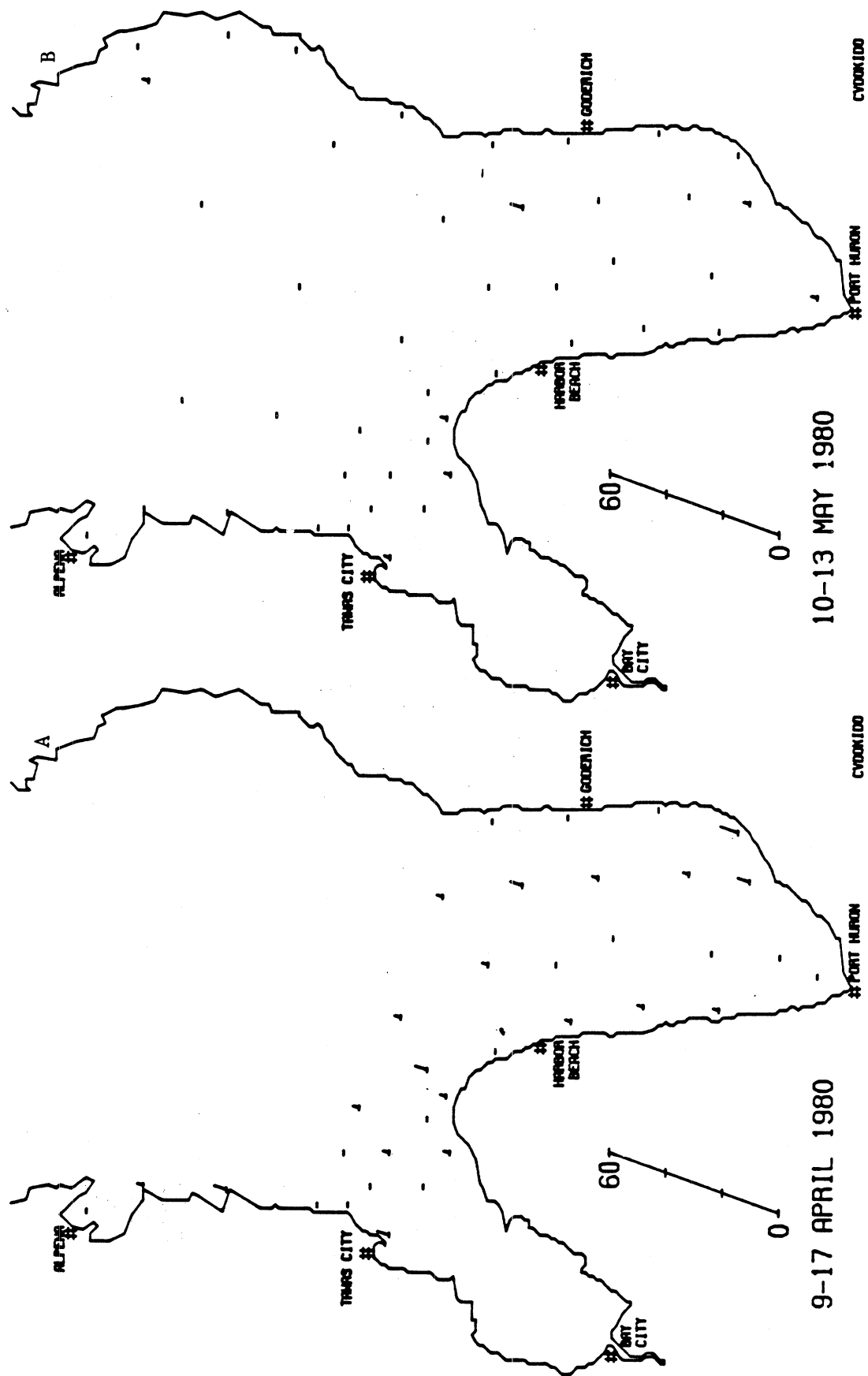


FIG. 52. Distribution of *Chrysococcus dokidophorus*.

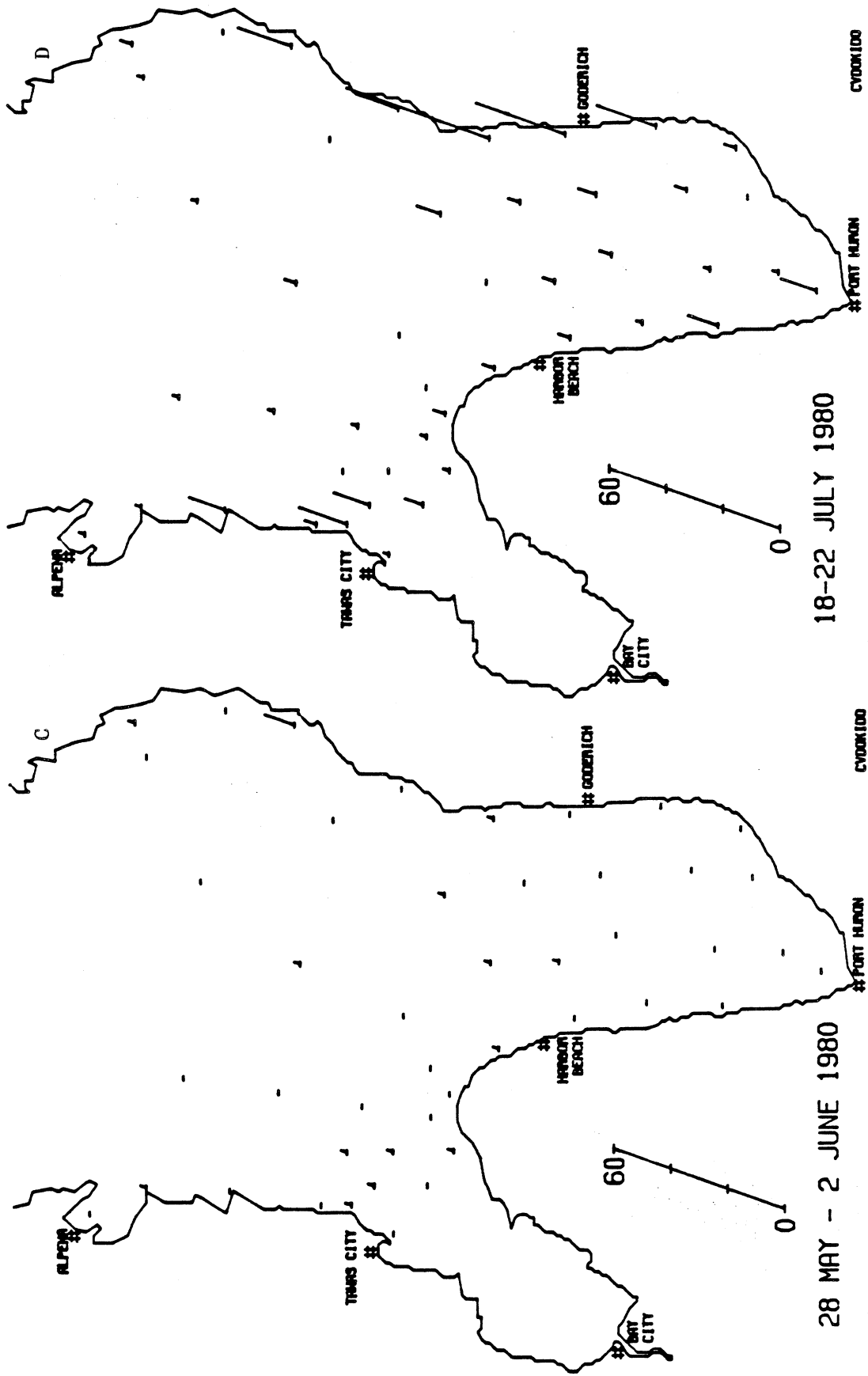


FIG. 52. (continued)

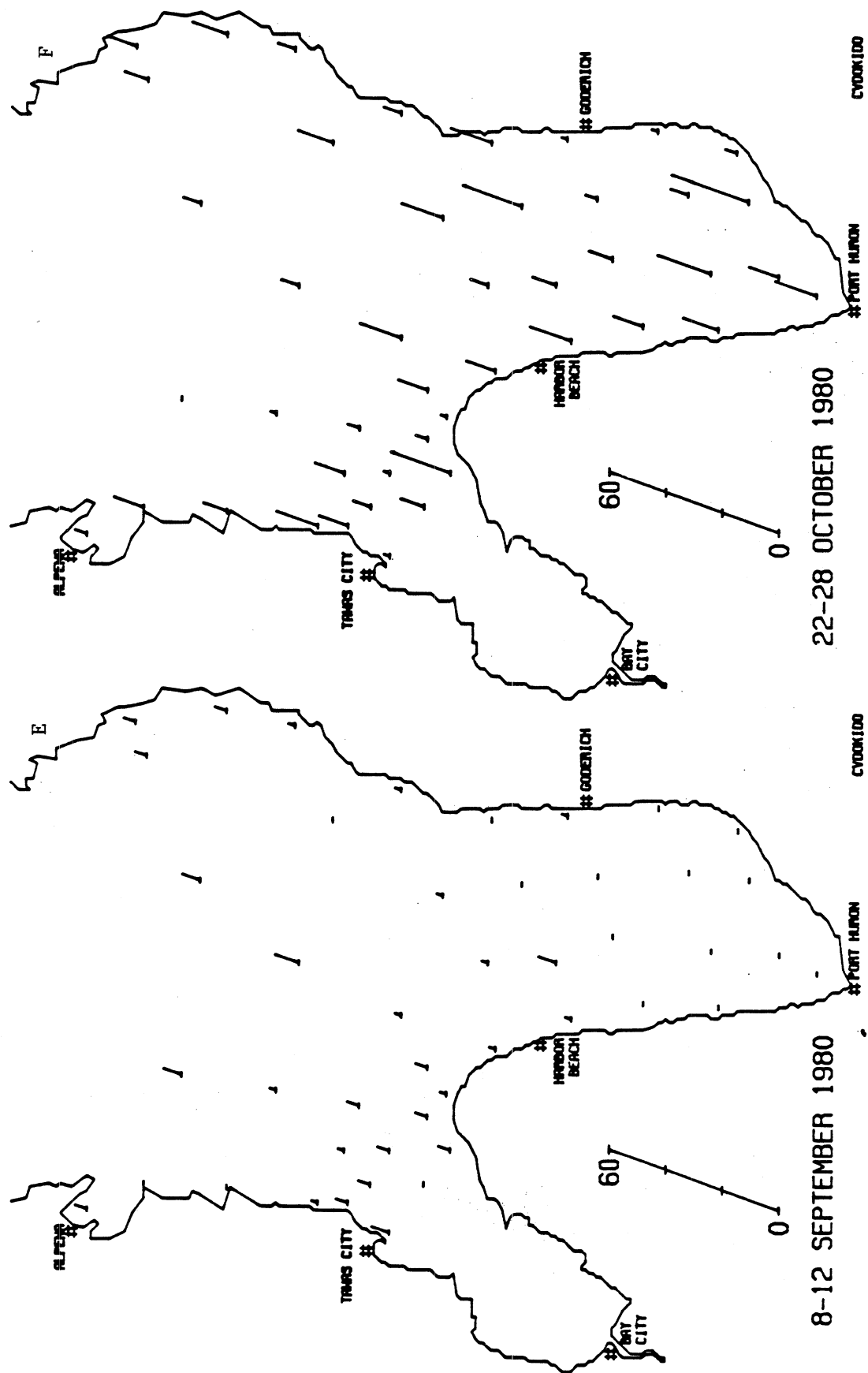


FIG. 52. (continued)

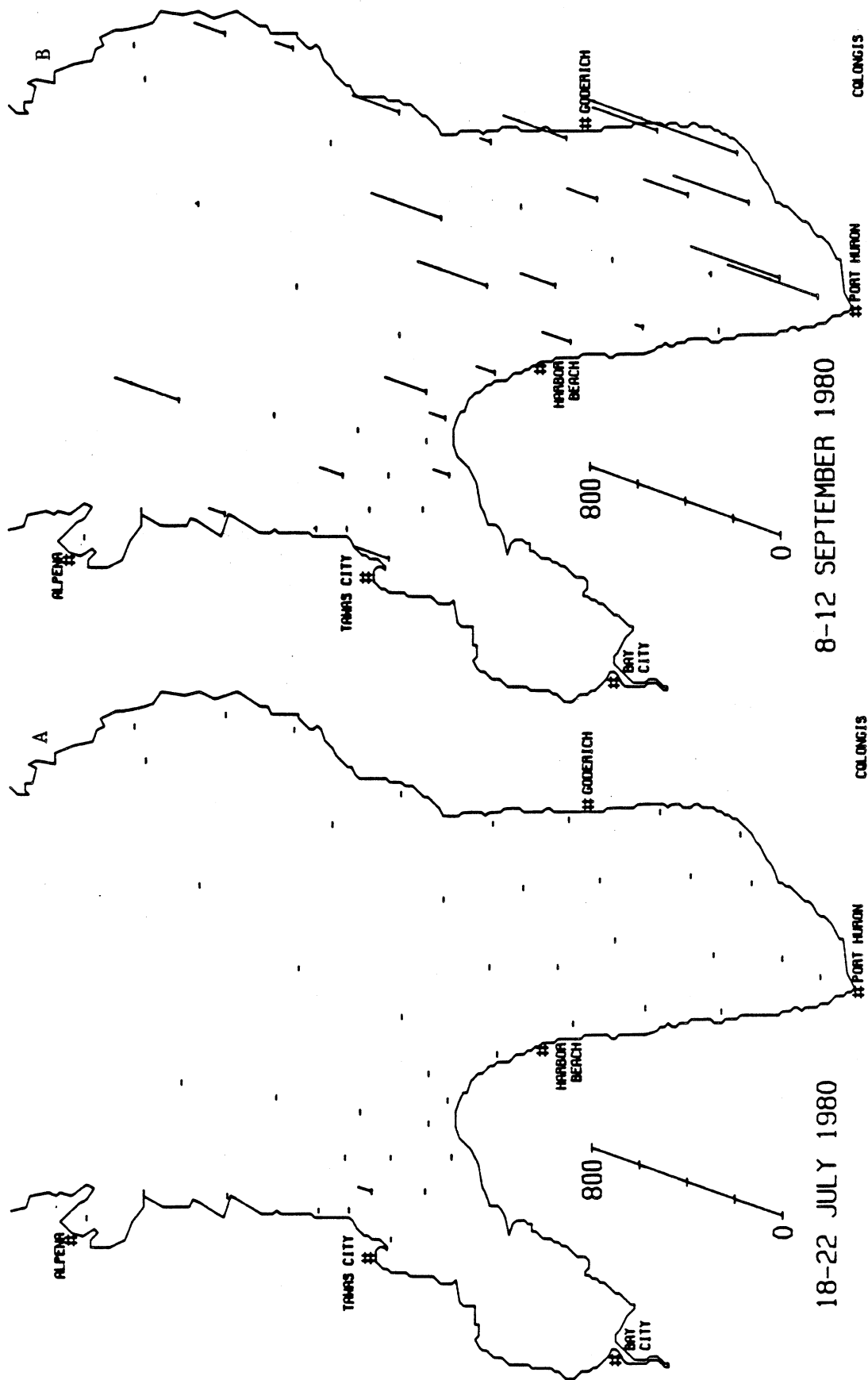


FIG. 53. Distribution of *Chrysosphaerella longispina*.

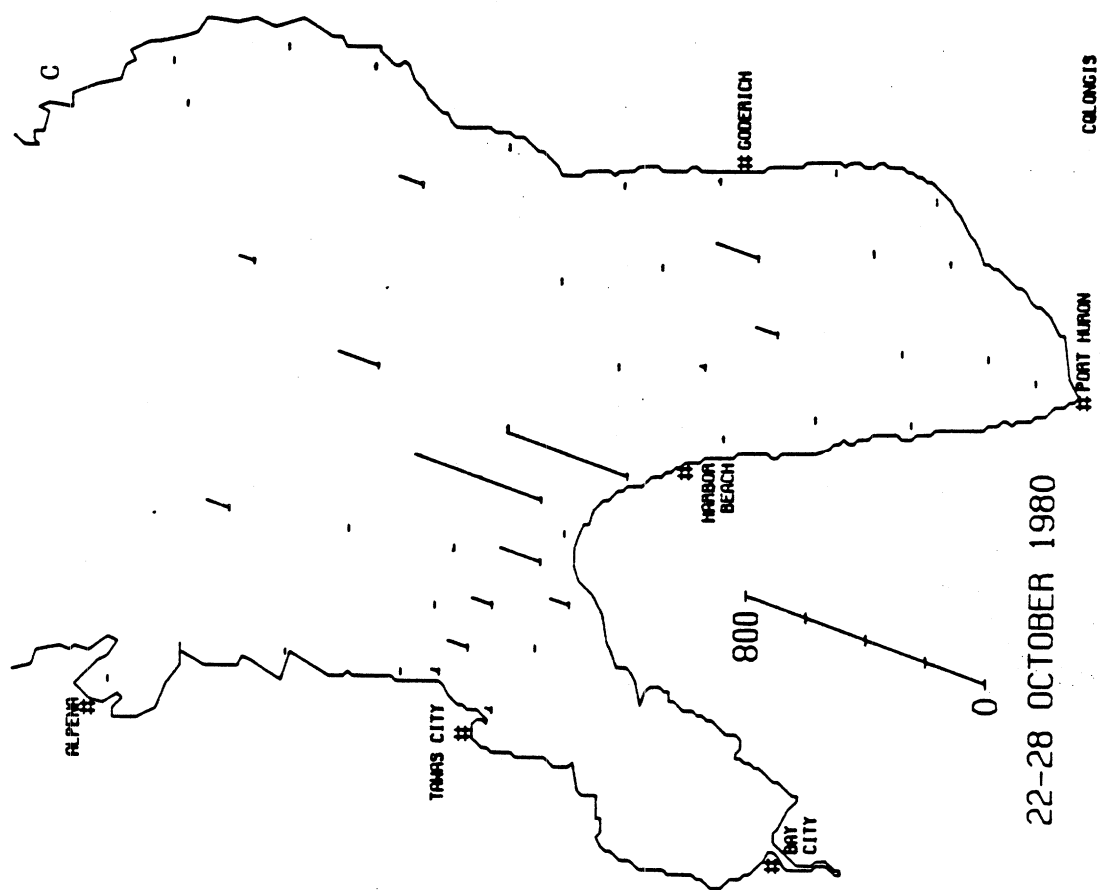


FIG. 53. (continued)

southern basin, particularly in the extreme southern sector. Reduced concentrations were recorded for October (Fig. 53C) and, although it was present in all sectors, C. longispina was especially abundant in the Saginaw Bay interface.

Dinobryon divergens--

D. divergens is a motile, colonial form which is the most commonly reported species of this genus from the Great Lakes. Historically, the arborescent colonies were observed in net plankton samples and led to Lake Michigan being deemed a "Dinobryon" lake (Ahlstrom 1936). For this study, its distribution was generally confined to the nearshore zone around the study area. During April (Fig. 54A), the Saginaw Bay interface waters exhibited the highest abundance of D. divergens for the year. One large population was also observed in the nearshore area north of Goderich. Low abundances were observed from May through July (Figs. 54B-54D) with occurrences for the most part, again, in nearshore areas and waters adjacent to Saginaw Bay. During September (Fig. 54E), it was noted in nearshore areas in moderately low abundance but occurrences were centered in the southern basin. Only sporadic occurrences at moderate abundances were seen in October (Fig. 54F).

Monochrysis aphanaster--

This chrysophyte has not been previously reported from the Great Lakes, although it was commonly found during this study. In April (Fig. 55A), moderate abundances were observed and it was widely distributed over the study area. During May (Fig. 55B), populations were most abundant in the Saginaw Bay interface zone and near Alpena. In June (Fig. 55C), higher abundances were recorded and were concentrated in the nearshore zones around the study

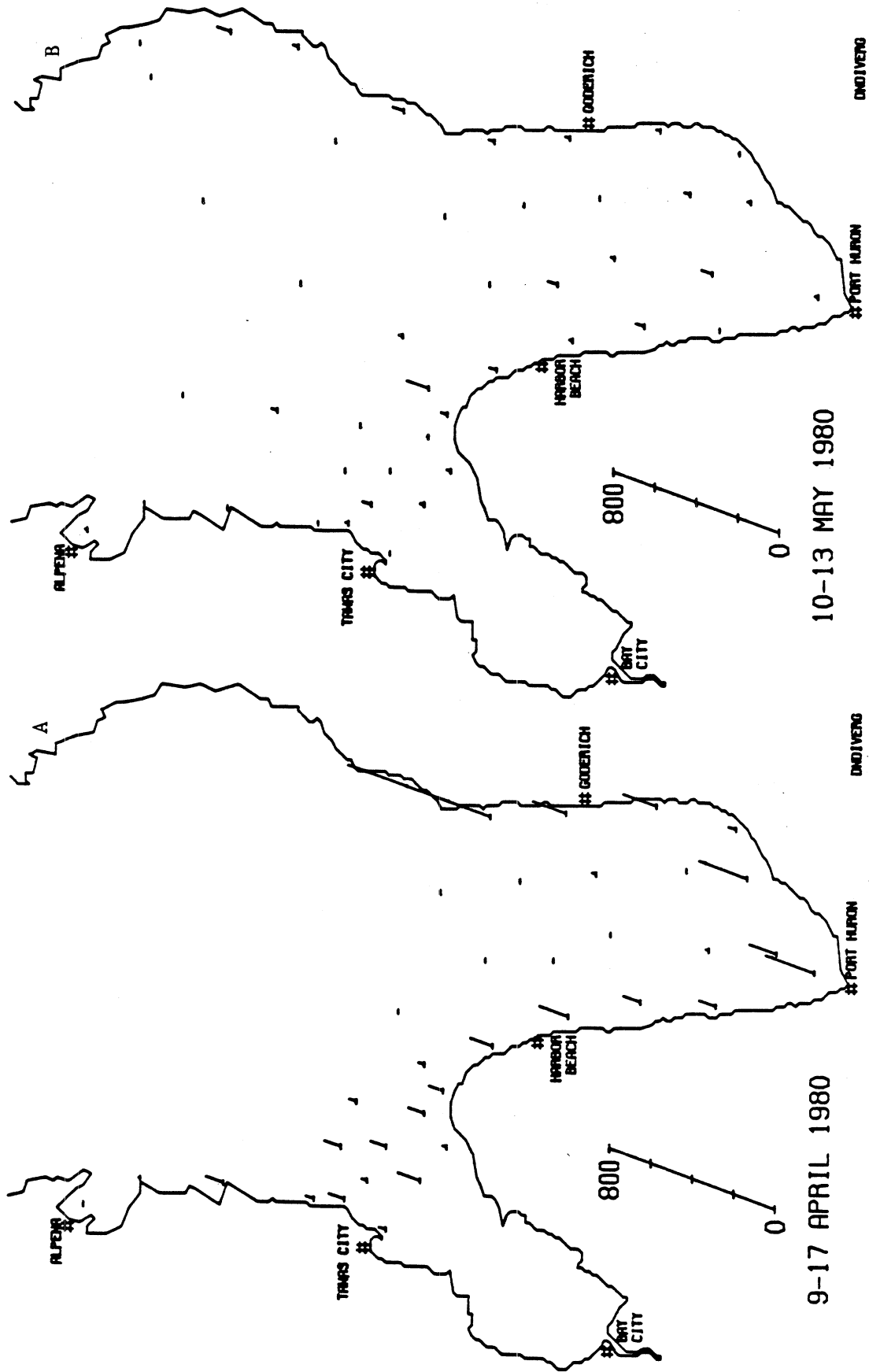


FIG. 54. Distribution of *Dinobryon divergens*.

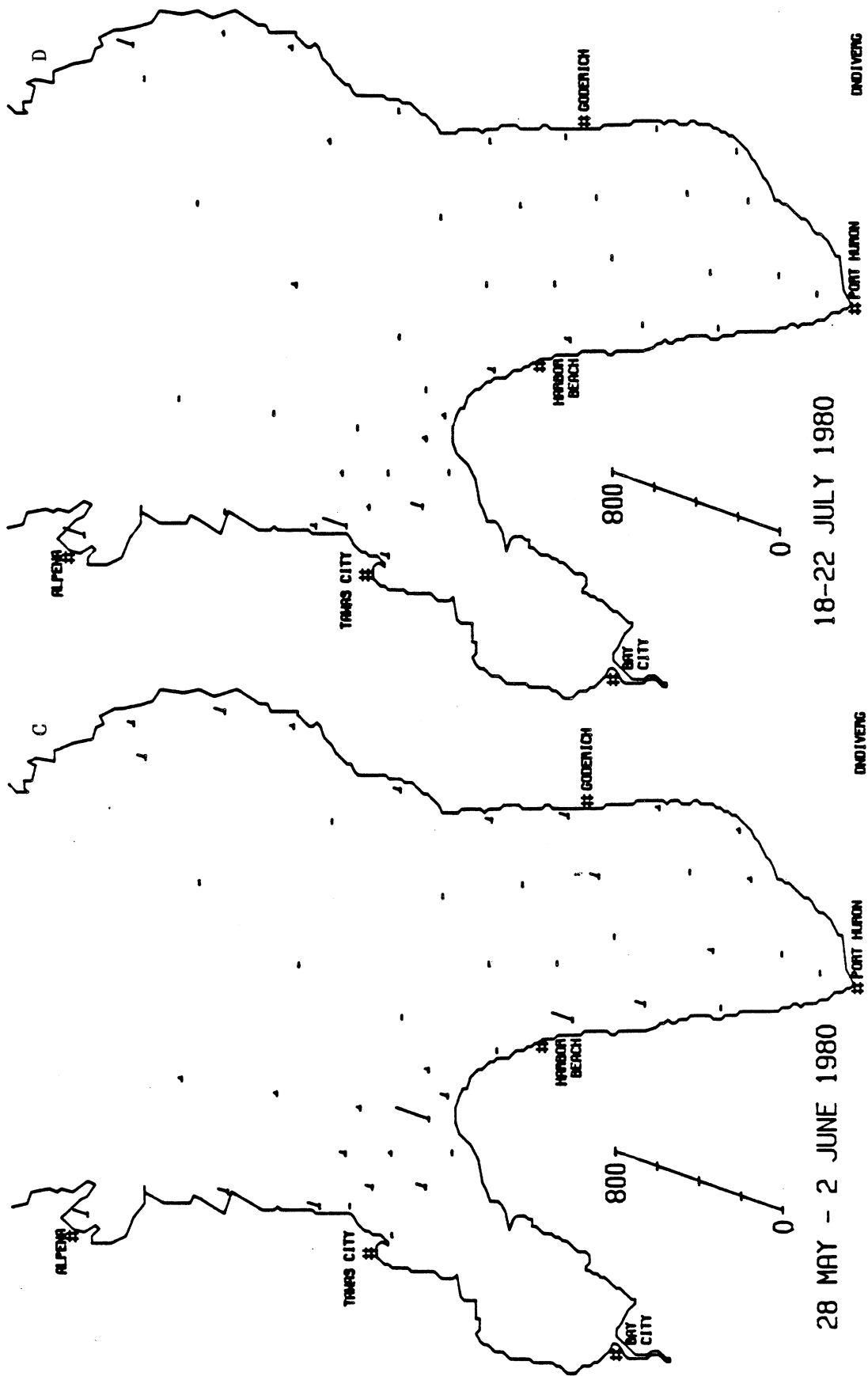


FIG. 54. (continued)

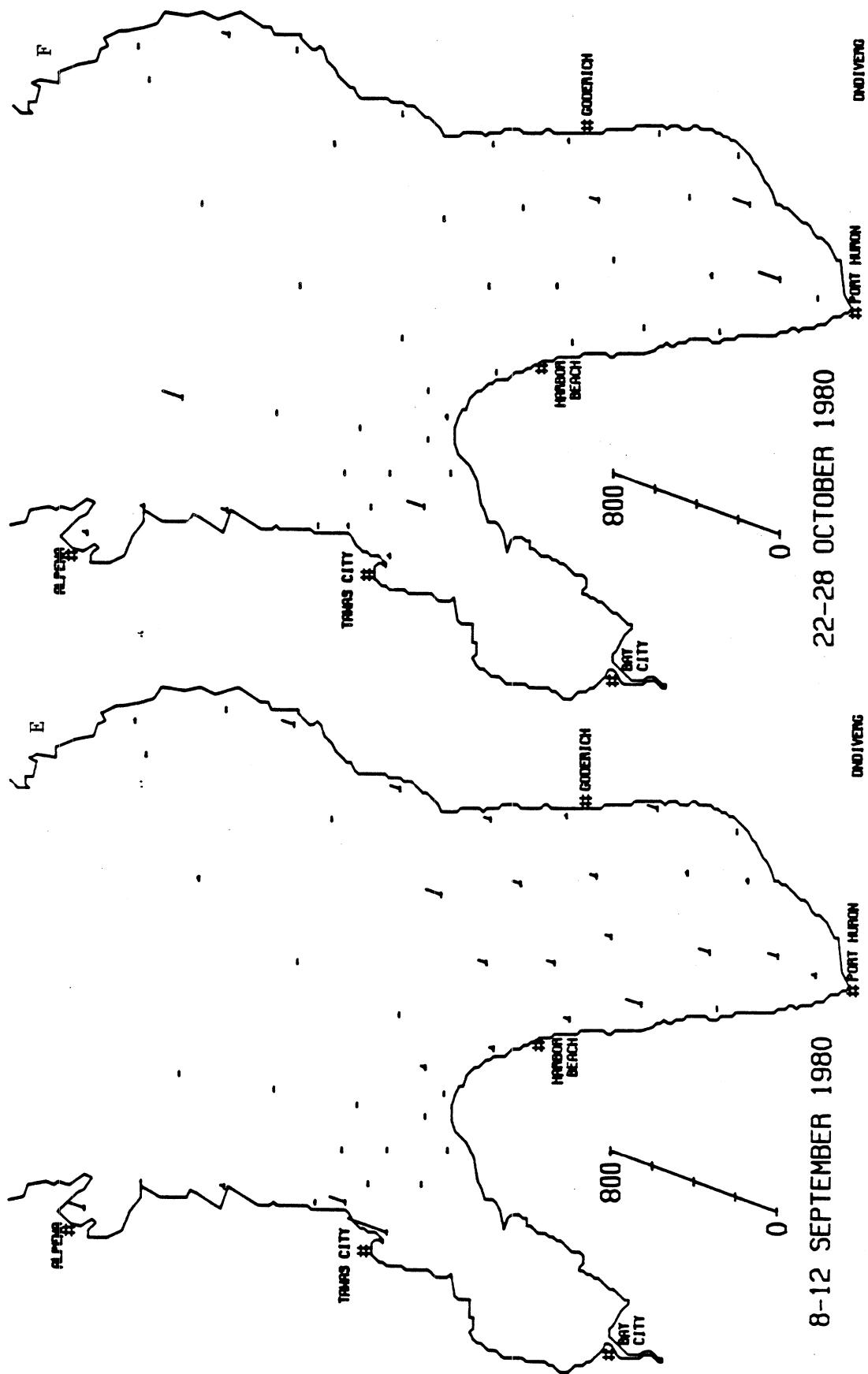


FIG. 54. (continued)

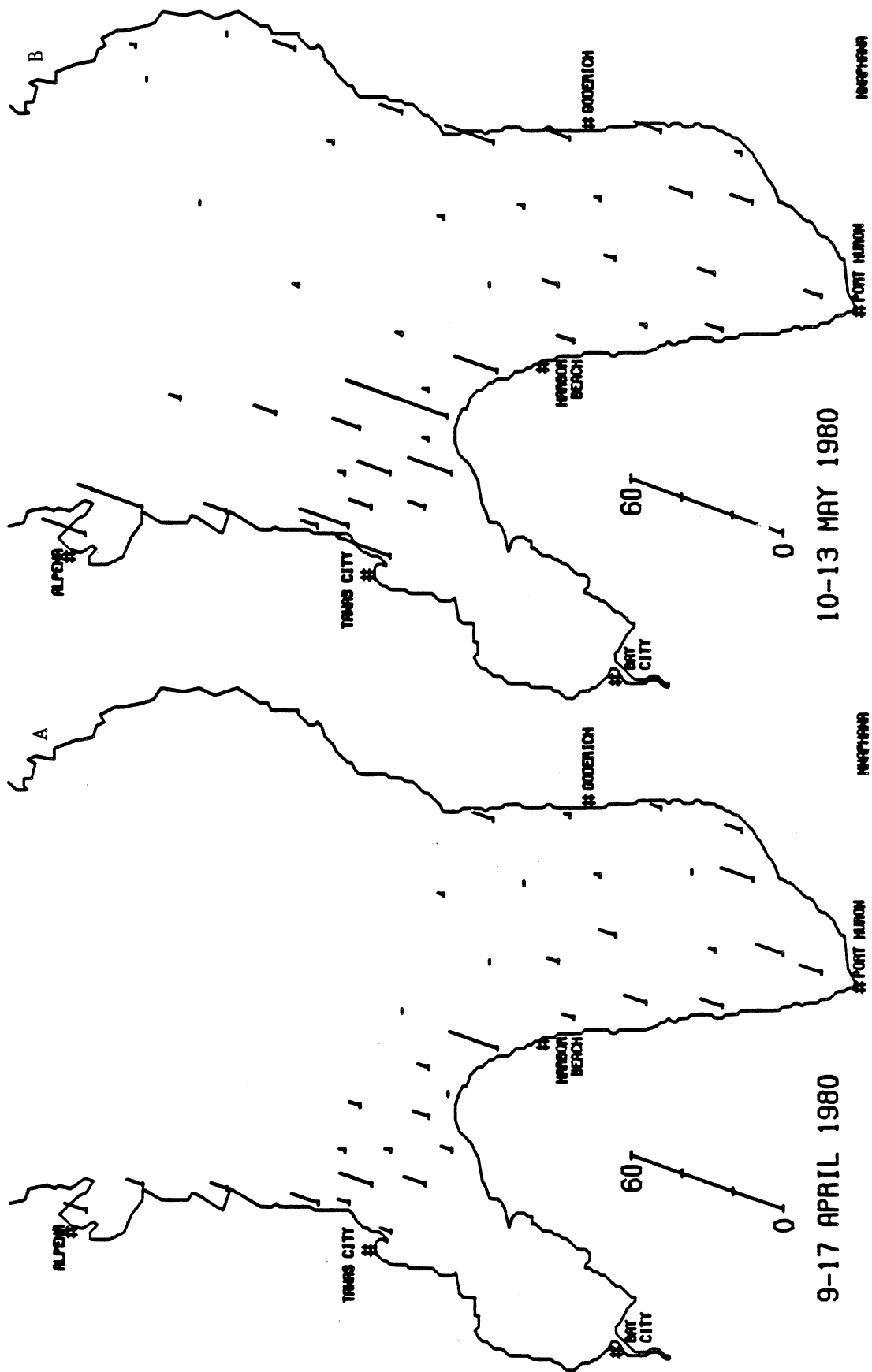


FIG. 55. Distribution of *Monochrysis aphanaster*.

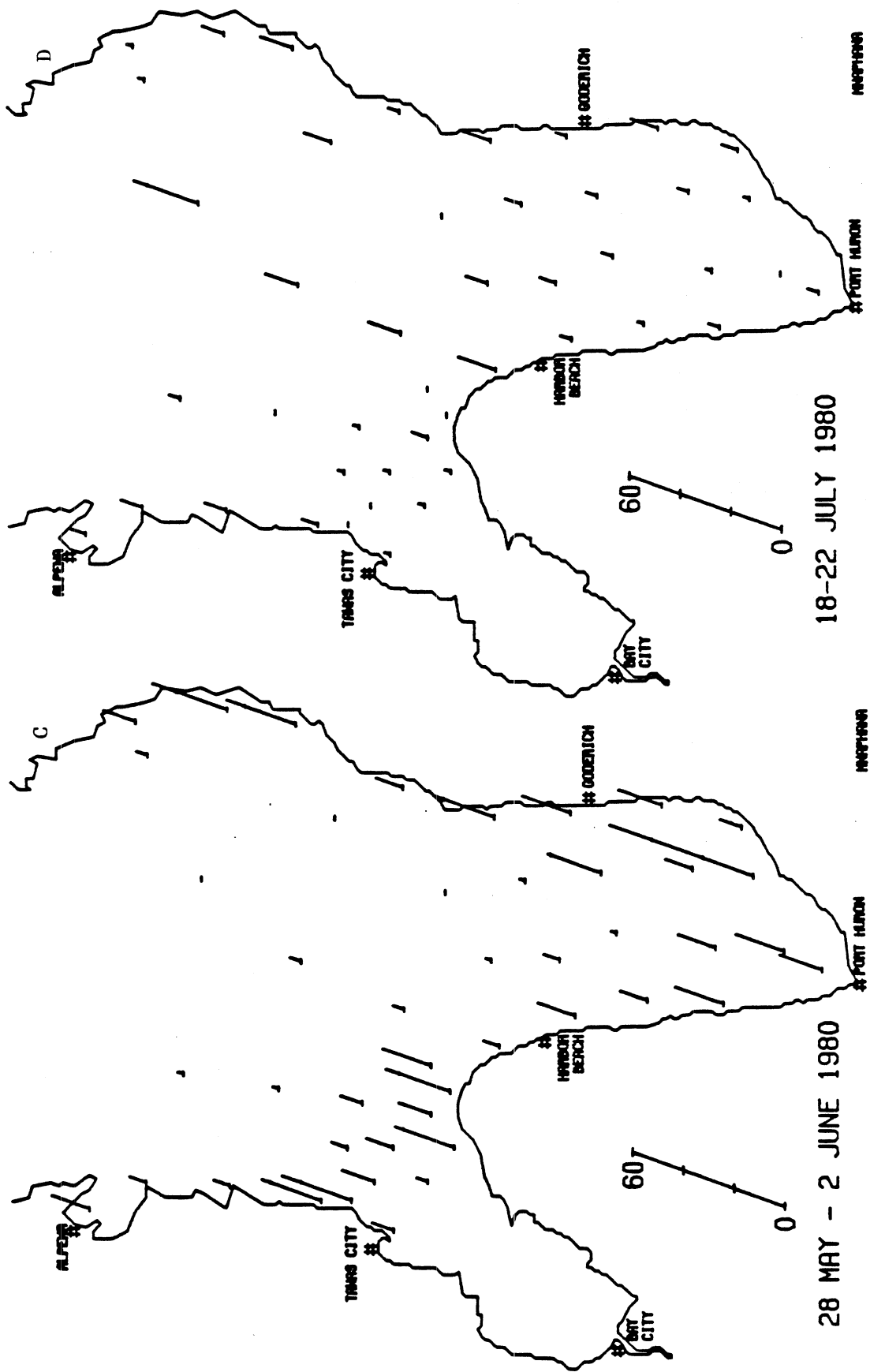


FIG. 55. (continued)

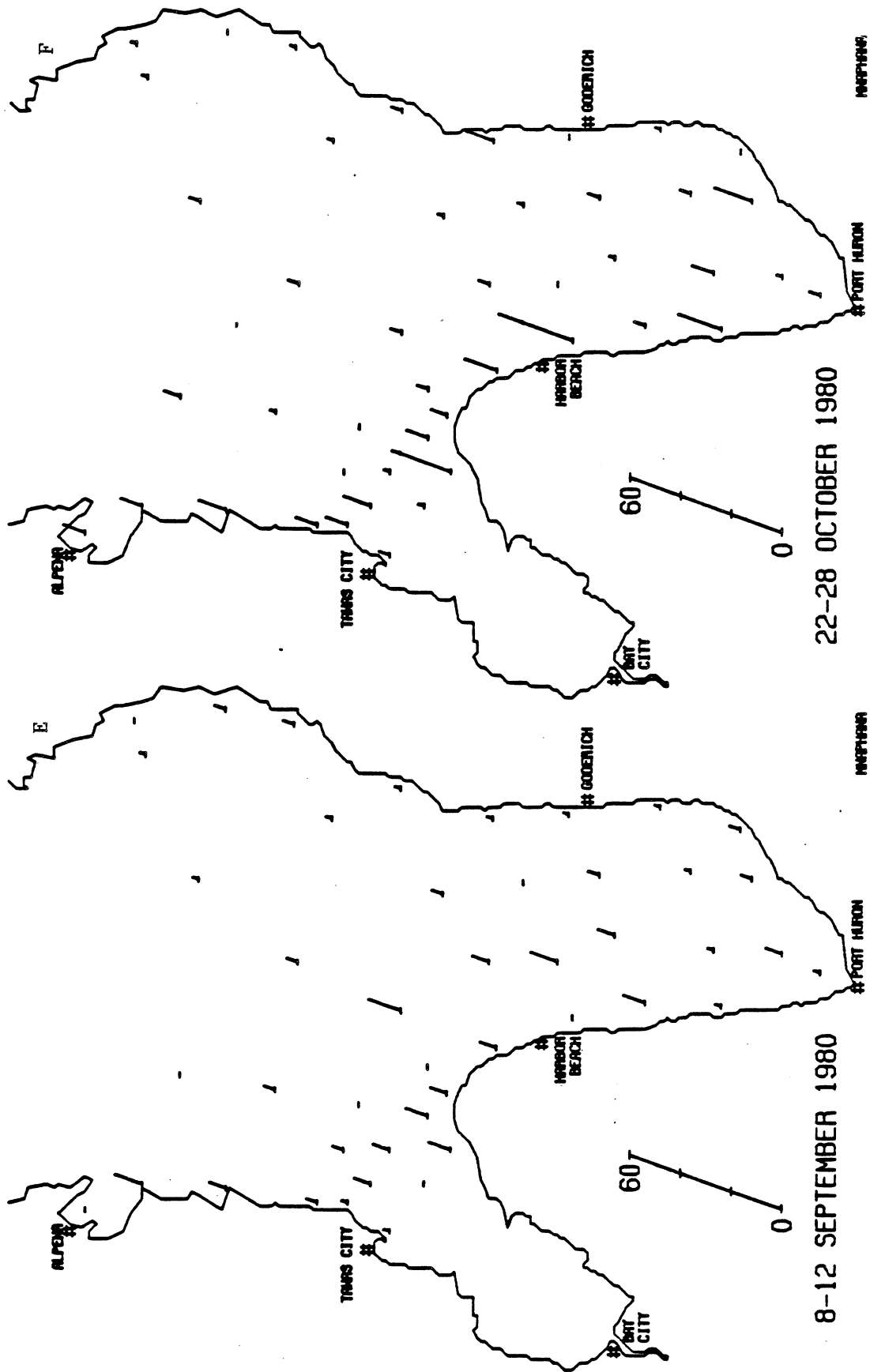


FIG. 55. (continued)

area as well as in the Saginaw Bay interface. During July (Fig. 55D), it was widely distributed at comparatively low abundances, exhibiting highest standing crops in the mid-central basin. In September (Fig. 55E), it occurred in all sectors of the lake at low abundances but showed no apparent distributional trend. Highest concentrations were observed in the U.S. nearshore area for October (Fig. 55F), but it was observed throughout the study area.

Ochromonas sp. #2--

This small flagellate form has not been satisfactorily aligned with a described species. On average, it was the most abundant chrysophyte observed in the study area and exhibited a bimodal abundance periodicity. It was previously reported from Lake Huron as Ochromonas sp. #1 (Stoermer and Kreis 1980). In April (Fig. 56A), it was widely distributed over the entire study area. Highest abundances were seen between Alpena and Tawas City in the nearshore zone, outer Saginaw Bay, and north of Goderich. During May (Fig. 56B), it was again well represented throughout the study area, with greatest cell numbers in Saginaw Bay and adjacent waters. Reduced abundances were observed in June (Fig. 56C), particularly along the southern U.S. shore and in Saginaw Bay. Greatest cell densities for this month were recorded in the offshore waters of the central basin. During July (Fig. 56D), populations had been reduced and were seen in very low abundances in the offshore central basin. During September (Fig. 56E), few or no occurrences were recorded. Modest abundance was observed in October (Fig. 56F), with highest cell counts occurring in outer Saginaw Bay and the interface zone.

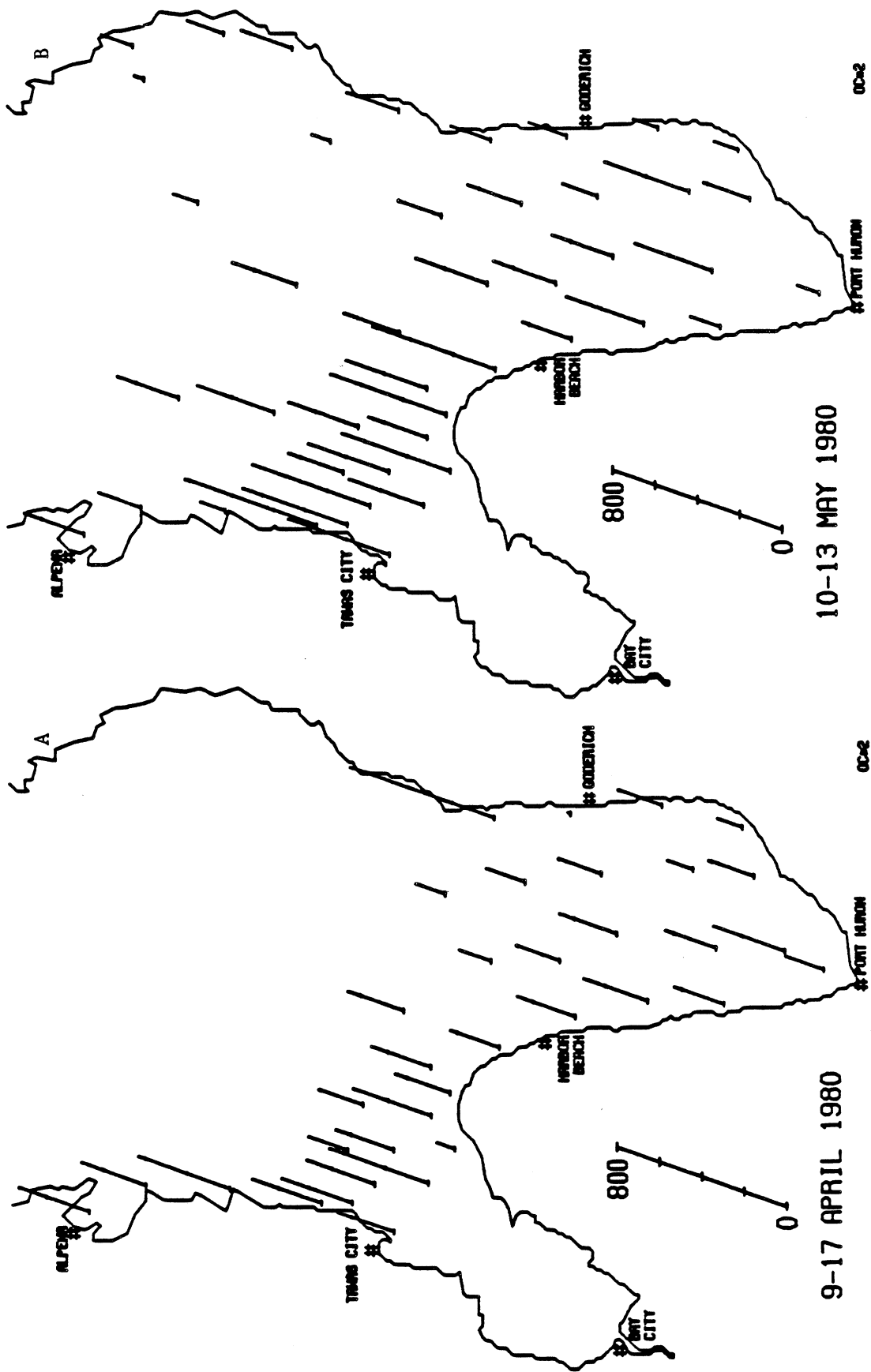


FIG. 56. Distribution of *Ochromonas* sp. #2.

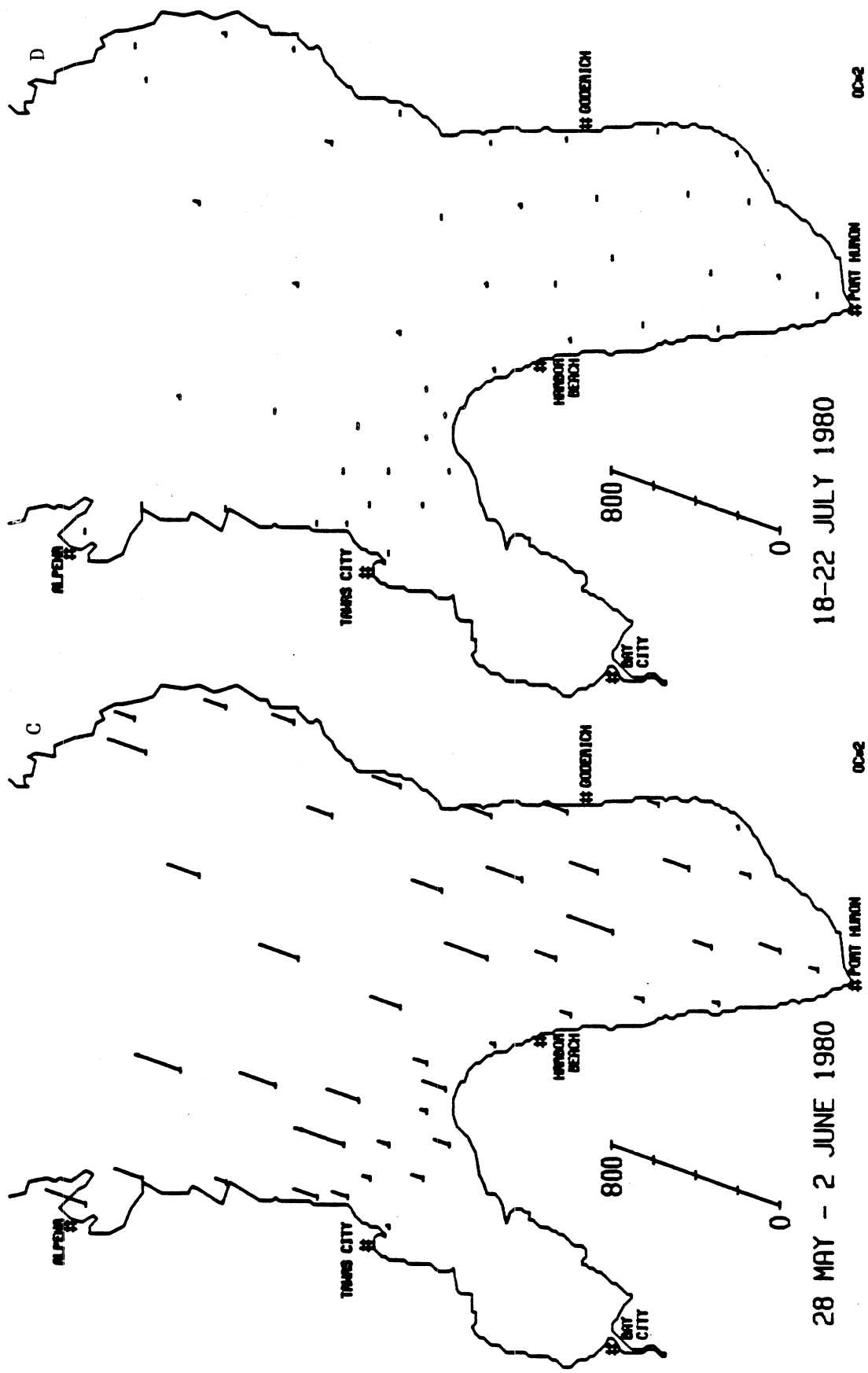


FIG. 56. (continued)

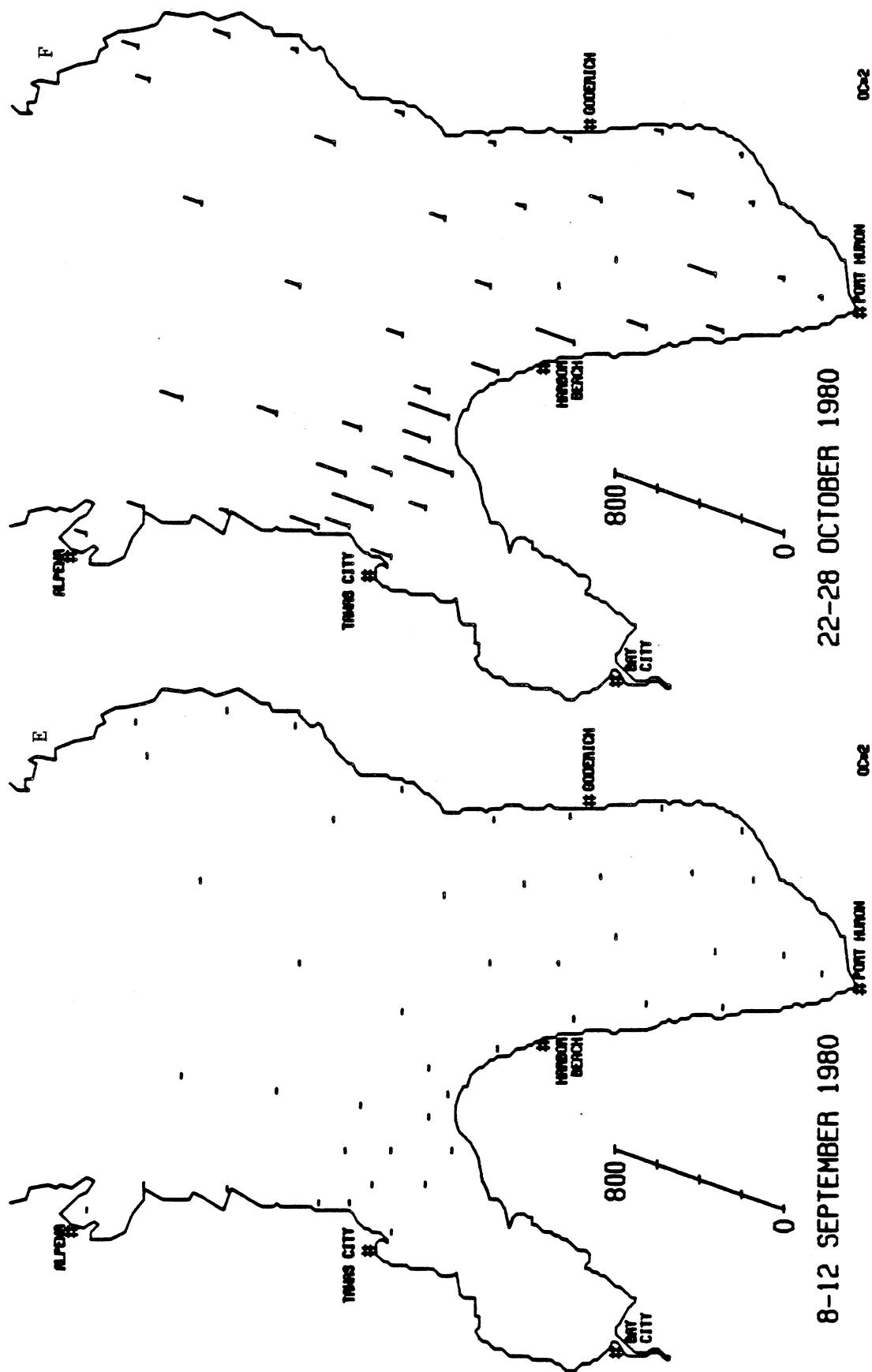


FIG. 56. (continued)

### Cryptophyta - Cryptomonads

Some element of this flagellate group is usually present in any collection from the Great Lakes. Cryptomonads were present during all sampling periods in southern Lake Huron. They are generally found in greatest abundances in nutrient enriched areas, although most species can be observed in areas ranging anywhere from eutrophic to oligotrophic (Huber-Pestalozzi 1968). This is particularly evident in the Great Lakes. In a number of cases, what appears to be the same species is reported from Lake Erie as well as from Lake Superior (Munawar and Munawar 1976, 1978). In southern Lake Huron, cryptomonads show a seasonal cycle but were evenly distributed throughout the study area during any given month. During April (Fig. 57A), abundance was moderate and uniformly distributed over the study area. Increased abundances were recorded in May (Fig. 57B), comprising the highest values for the season. Greatest abundance was observed along the Canadian coastal zone in the southern basin, with slightly lower concentrations in Saginaw Bay and adjacent waters. In general, abundance was lower in the central basin compared to the southern. Cell densities were slightly reduced in June (Fig. 57C). Distribution was generally uniform, excepting low values in the Canadian nearshore zone, where abundance was high during the preceding sampling period. Reduced abundance and the lowest mean abundance for the year was seen in July (Fig. 57D). Abundances were centered in the offshore waters of both basins. In September and October (Figs. 57E and 57F), cryptomonads slightly increased and were widely distributed with the lowest abundance again in nearshore areas.

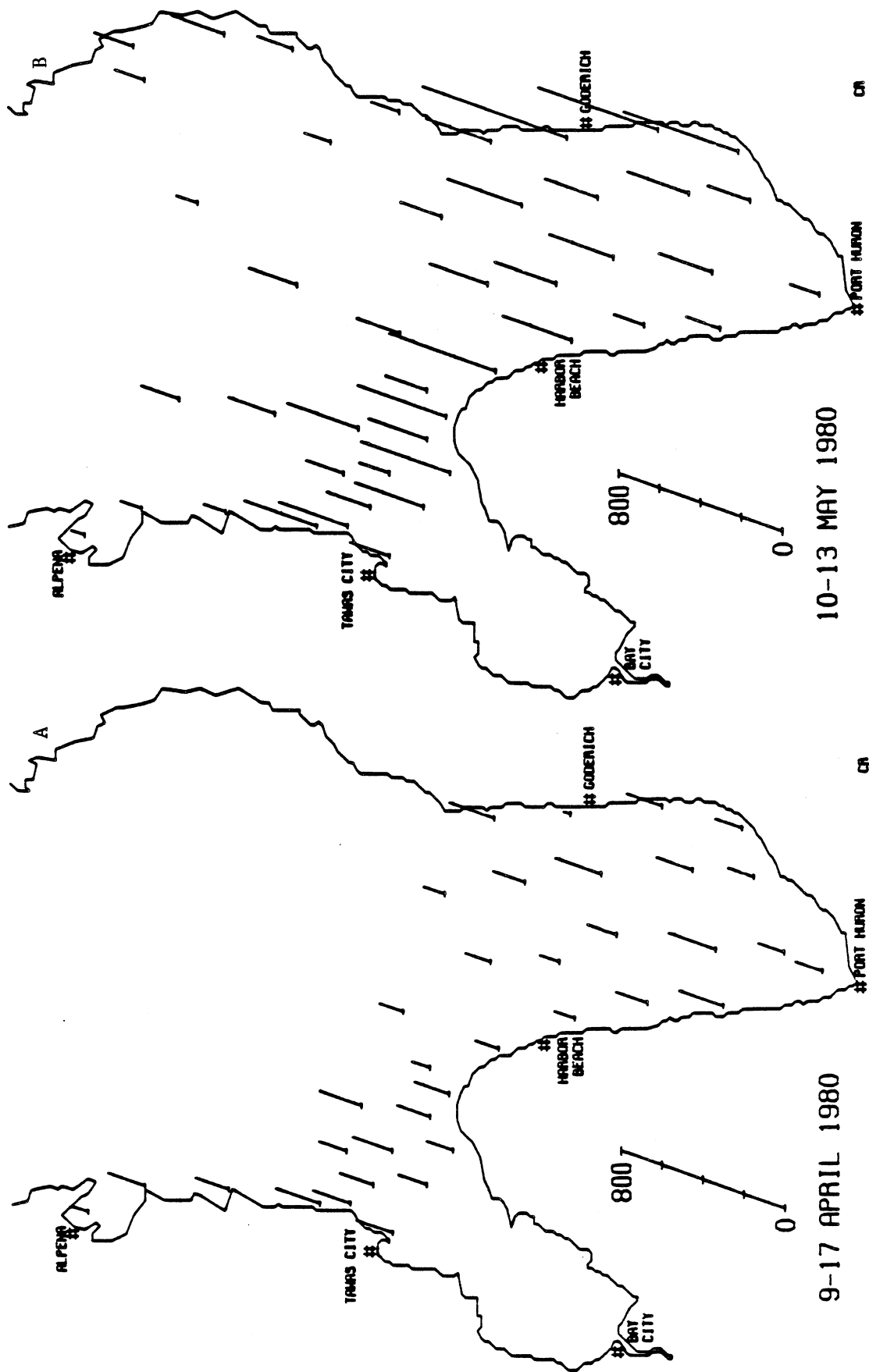


FIG. 57. Seasonal distribution and abundance trends (cells/mL) of cryptomonads, 1980.

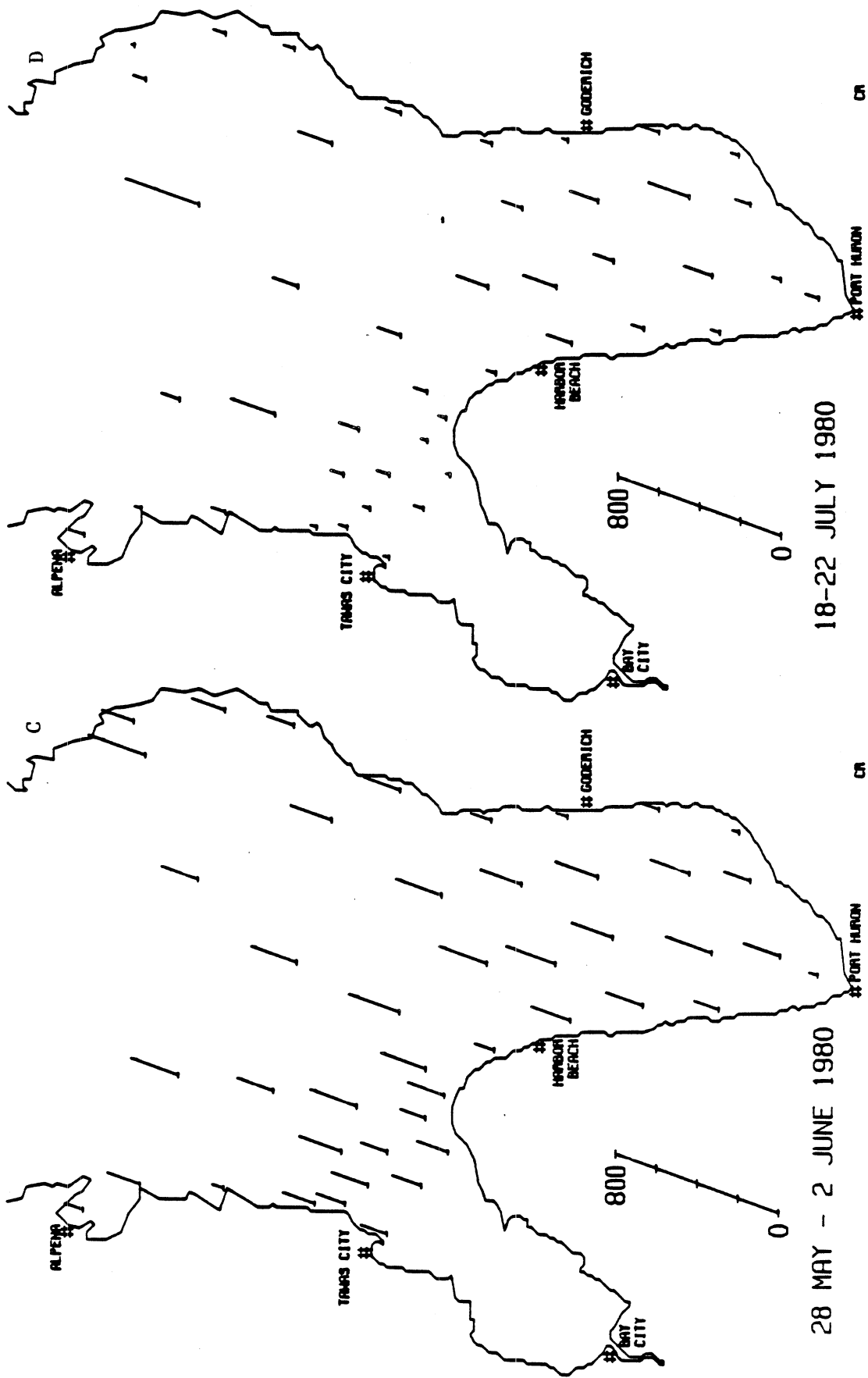


FIG. 57. (continued)

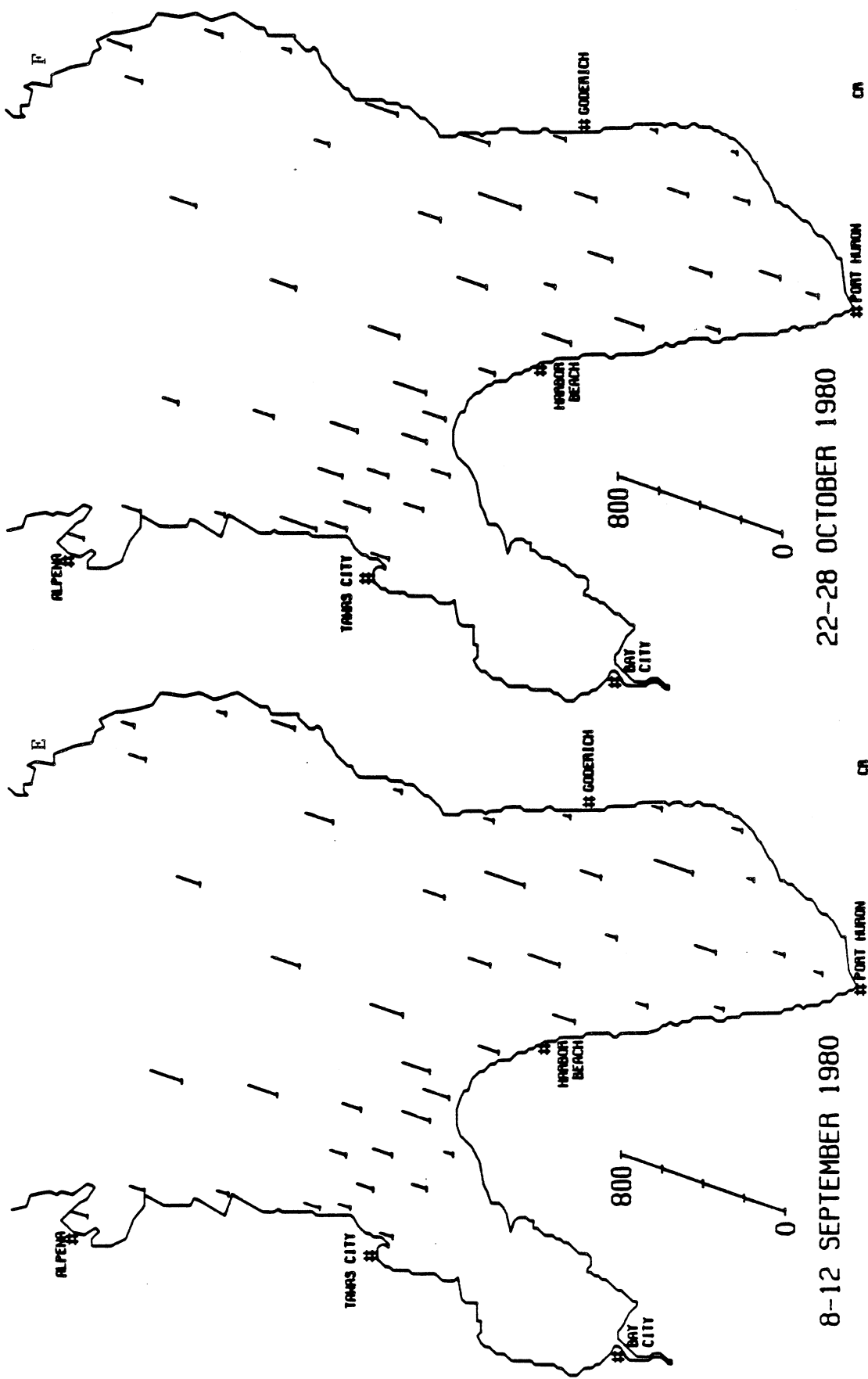


FIG. 57. (continued)

Chroomonas spp.--

Chroomonas is a flagellate genus which has only recently received adequate taxonomic attention in the Great Lakes. Most of the forms placed in this category can be best assigned to Chroomonas nordstedtii. In April (Fig. 58A) low abundance was observed, with highest abundances recorded in the nearshore zone south of Alpena and in the Saginaw Bay interface. It was well distributed in low cell numbers in the southern basin. In May (Fig. 58B), highest abundances for the season were recorded. Although widely distributed over the study area, greatest abundances were in the nearshore zones of the southern basin and in Saginaw Bay with distinctly lower abundance in the central basin. In June (Fig. 58C), lower standing crop values were observed. Highest abundances were found in the southern basin and in the Saginaw Bay interface zone. Conversely, in July (Fig. 58D), highest cell numbers were seen in the offshore waters of the central basin, although it was still widely distributed. During September and October (Figs. 58E and 58F), occurrences were observed over the entire study area in moderate to low abundance.

Cryptomonas ovata--

This species is one of the larger and more commonly reported cryptomonads from the Great Lakes. It has a world-wide distribution, being recorded from habitats which encompass the entire range of the trophic spectrum (Huber-Pestalozzi 1968). It has been recorded from all of the Great Lakes (Munawar and Munawar 1975) but may find its greatest abundance in enriched areas. In April (Fig. 59A), this species was fairly uniformly distributed throughout the southern basin but showed a very large peak in the nearshore zone north of Goderich. In May (Fig. 59B), highest cell numbers were seen in Saginaw Bay

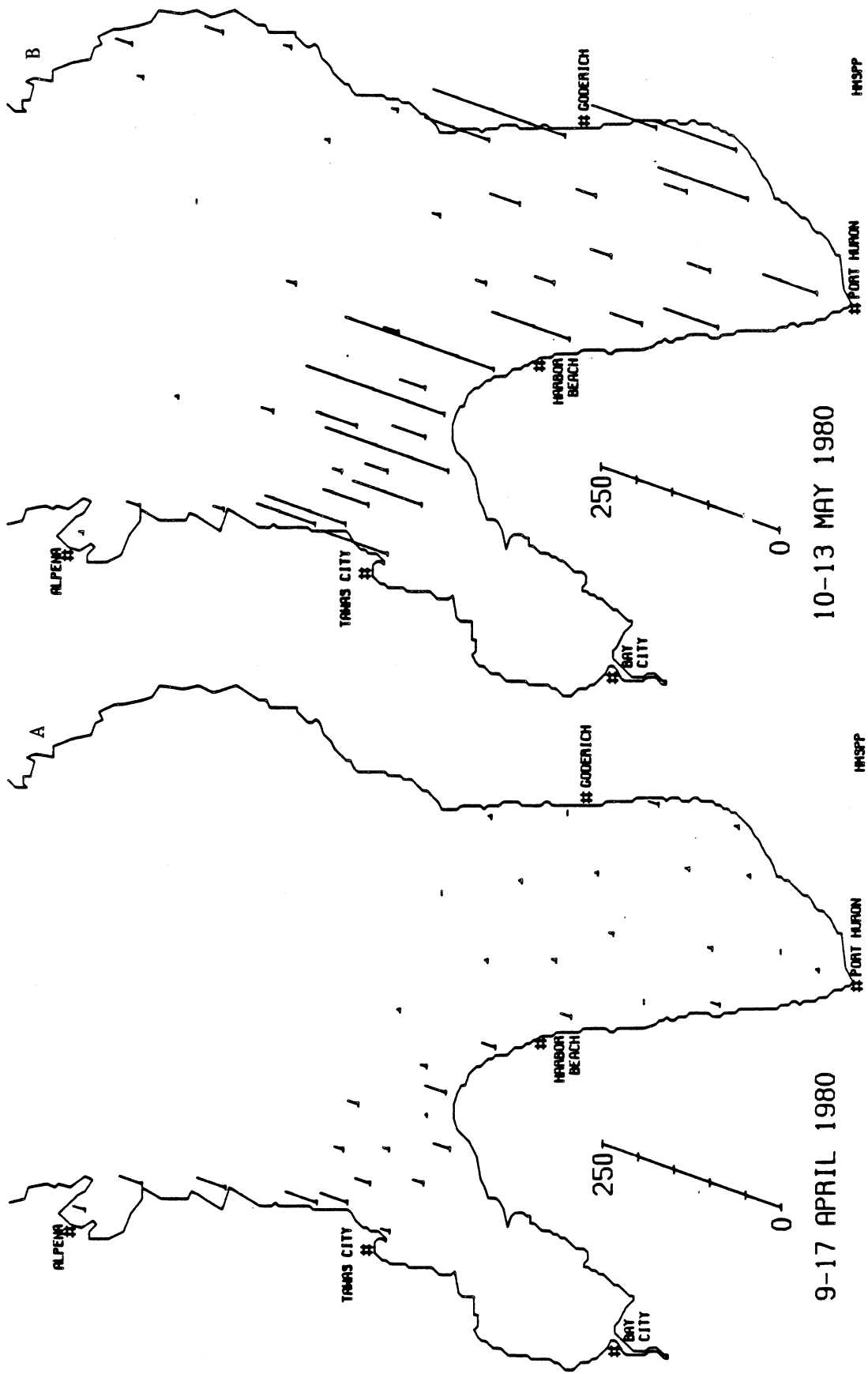


FIG. 58. Distribution of *Chroomonas* spp.

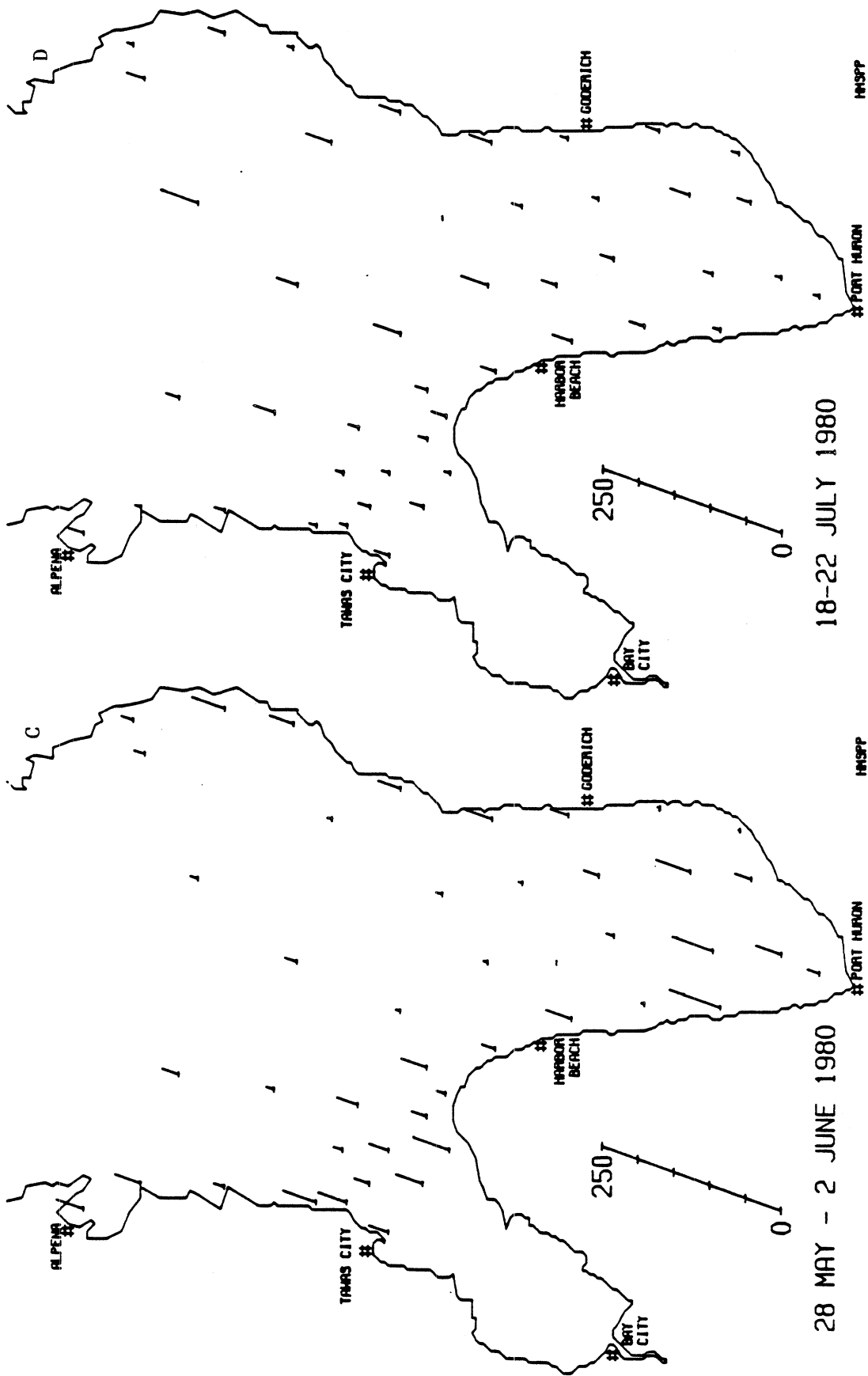


FIG. 58. (continued)

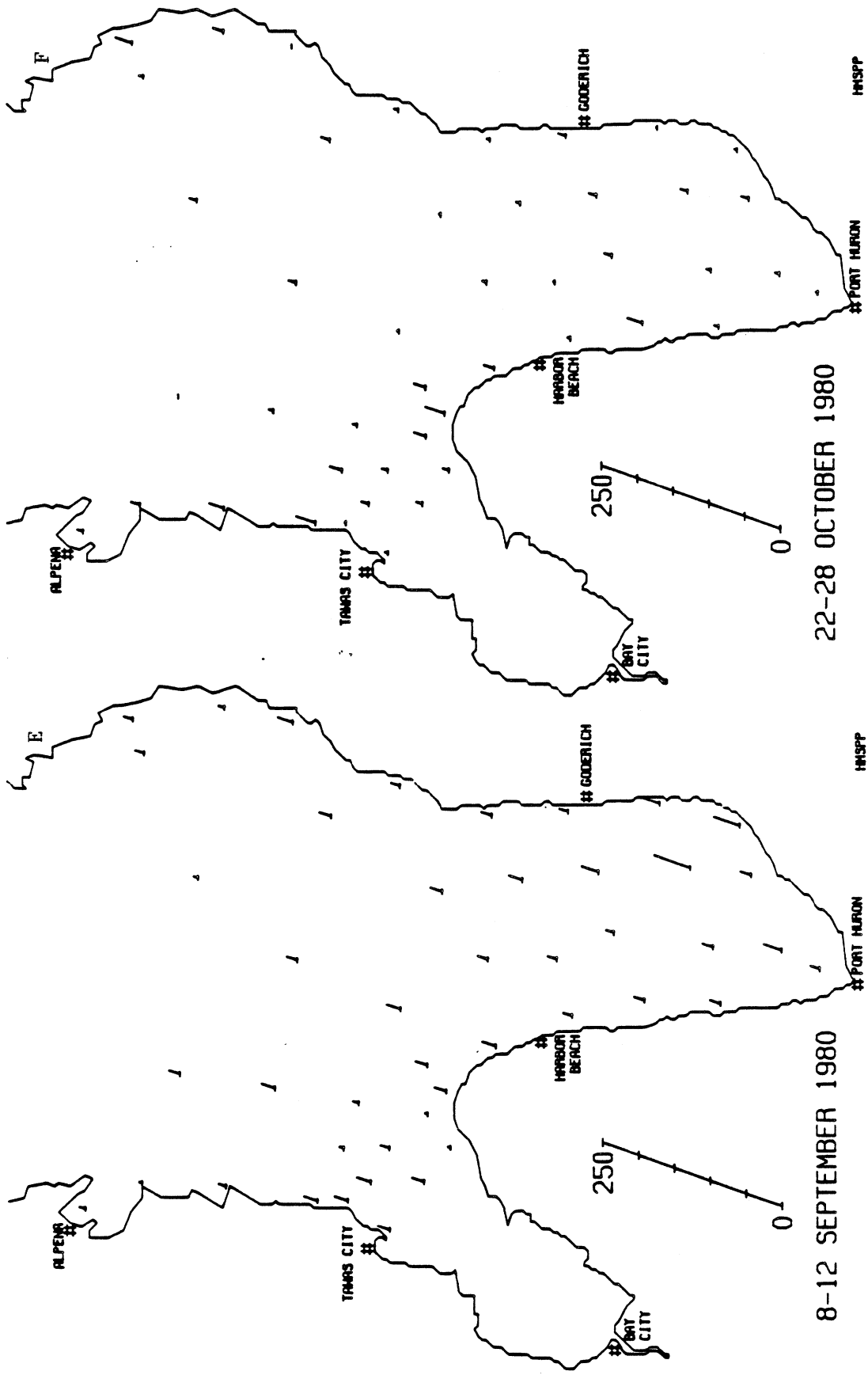


FIG. 58. (continued)

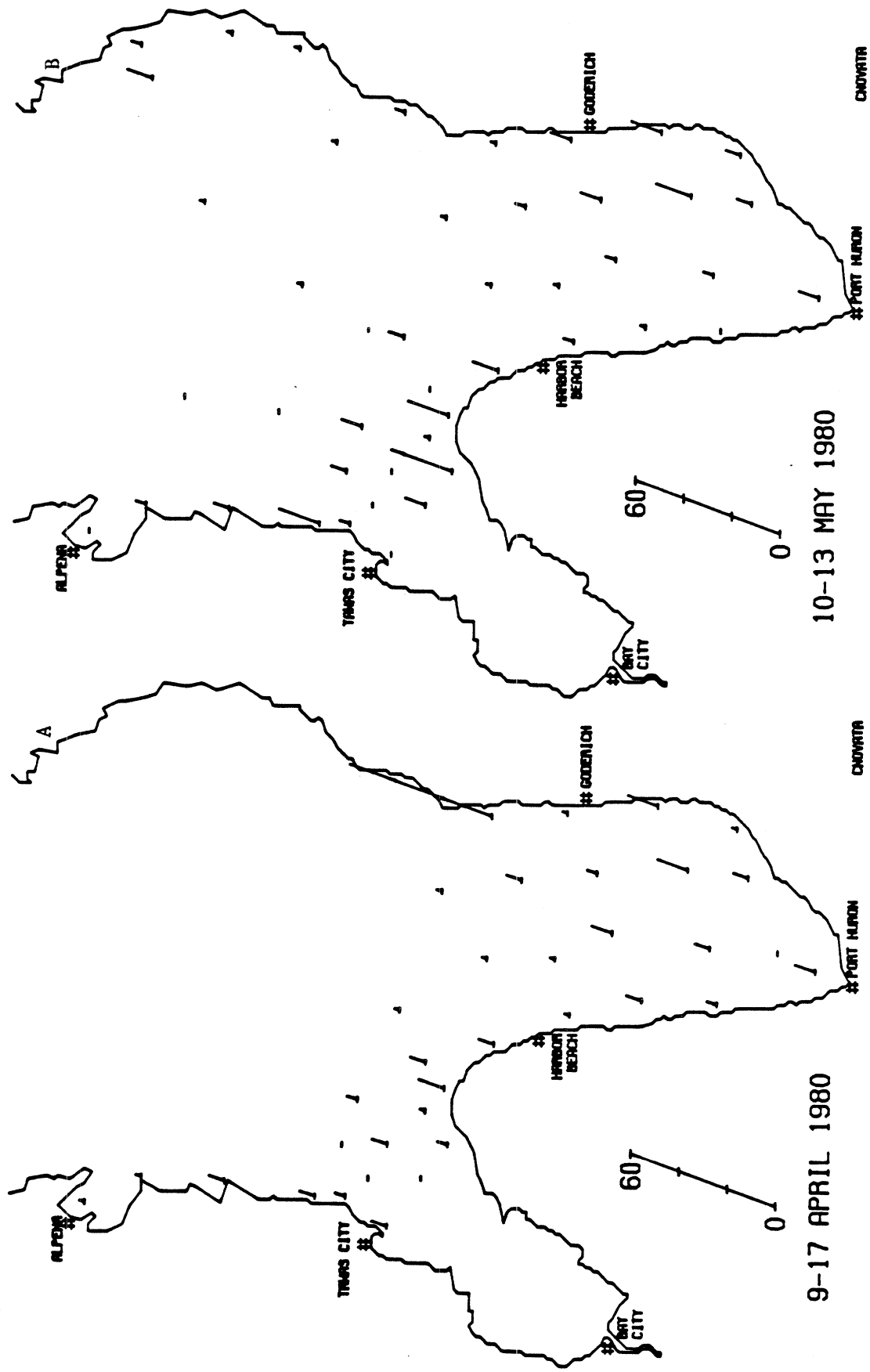


FIG. 59. Distribution of *Cryptomonas ovata*.

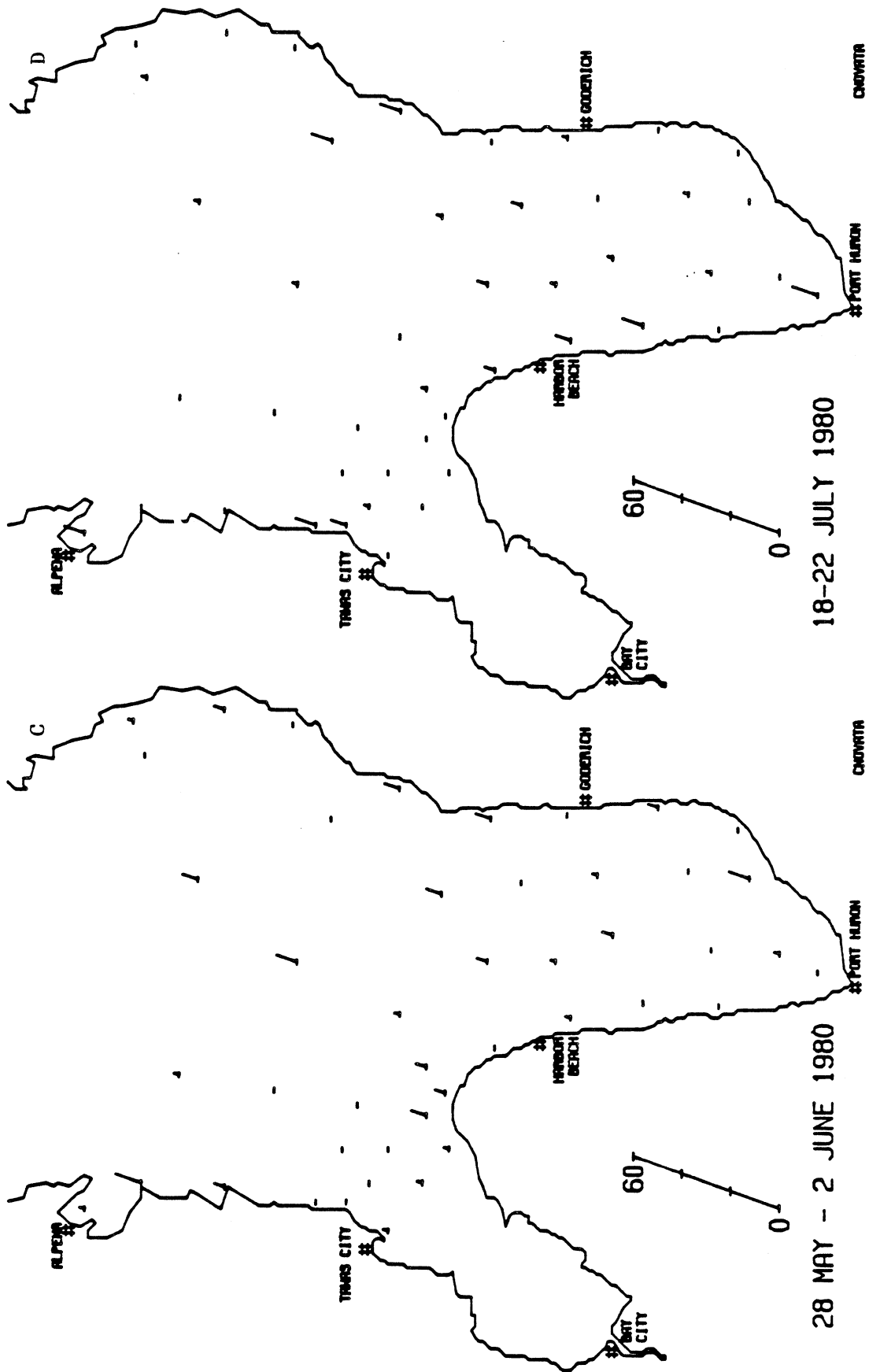


FIG. 59. (continued)

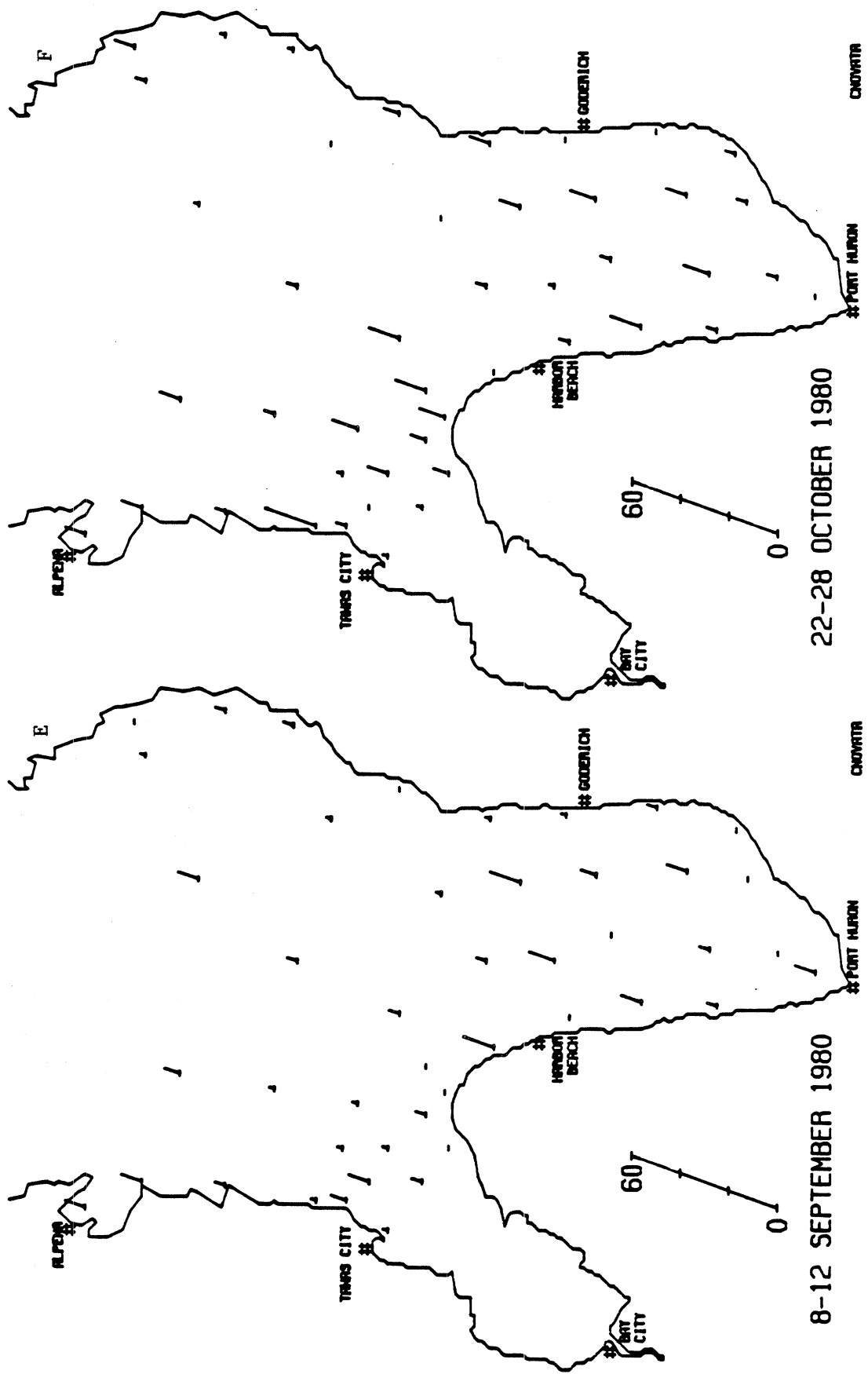


FIG. 59. (continued)

and in the waters just south of the bay, although distribution during this month was sporadic. Somewhat reduced abundances were observed in June and July (Figs. 59C and 59D), showing erratic distribution patterns. Slightly increased abundance was seen in September (Fig. 59E) and October (Fig. 59F). Distinct occurrence patterns were not evident in either month, but highest abundances seen in October were north of Tawas City and in the open waters east of Saginaw Bay.

Rhodomonas minuta--

Populations of Rhodomonas minuta, a small flagellate, has been reported from all of the Great Lakes (Munawar and Munawar 1975). It reaches highest abundances in slightly enriched areas. Uniform distribution at moderate abundances were observed for April (Fig. 60A). In May (Fig. 60B), populations were observed over the entire study area, with highest cell densities occurring in the Canadian sector of the southern basin. Reduced abundances were recorded for June (Fig. 60C), with the highest abundances for the cruise being noted in the offshore waters, particularly in the central basin. Greatly reduced occurrences and abundances were observed in July (Fig. 60D). Populations were centered in the offshore waters following the long axis of the lake. Modest abundances but a wider occurrence were observed in September (Fig. 60E), predominantly in the offshore waters. In October (Fig. 60F), slightly elevated abundances and a greater number of occurrences were observed, but generally in a uniform distribution.

Rhodomonas minuta var. nannoplanctica--

This variety of Rhodomonas has also been reported from all of the Great Lakes. Uniform distribution at low to moderate abundances was observed in

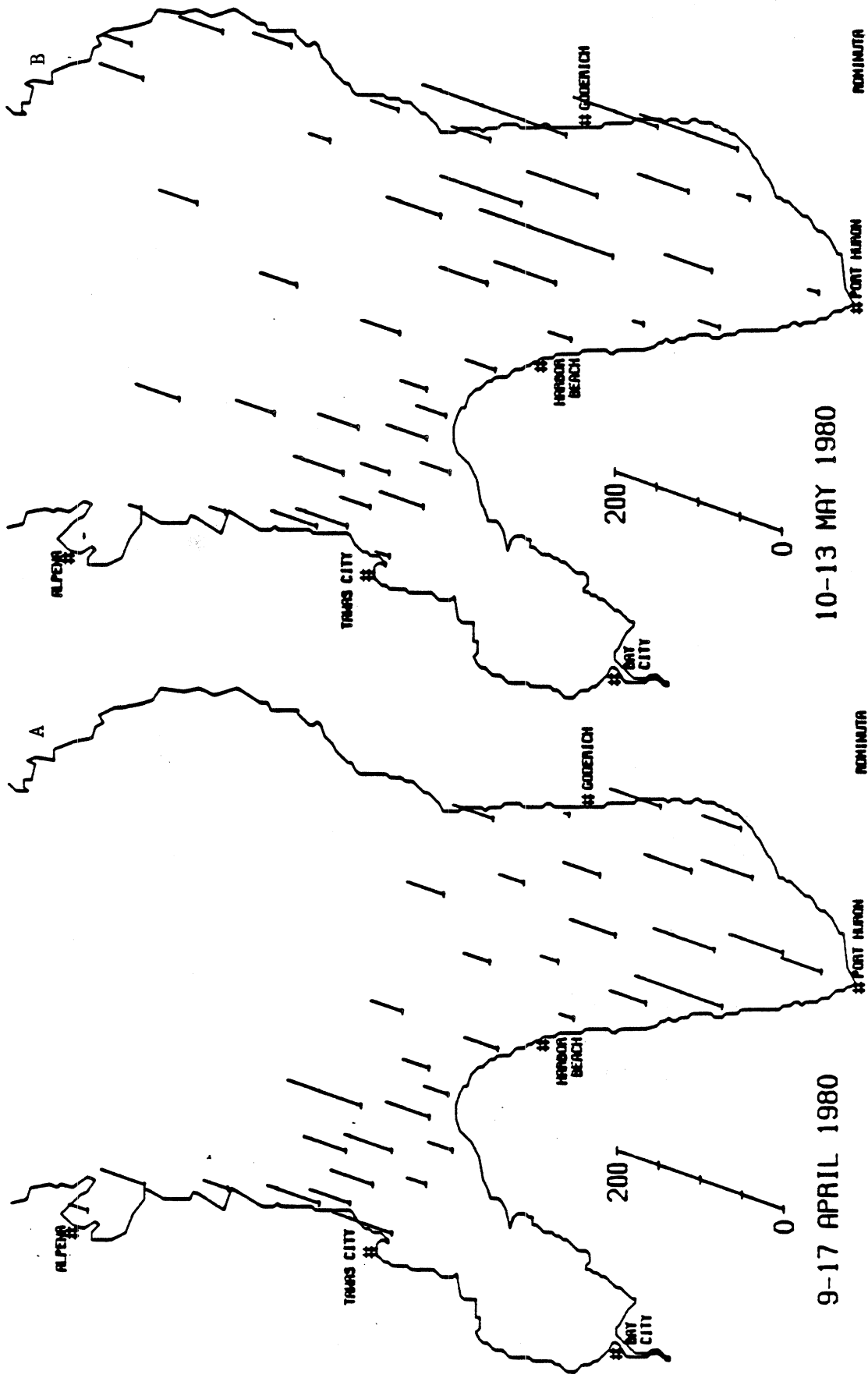


FIG. 60. Distribution of *Rhodomonas minuta*.

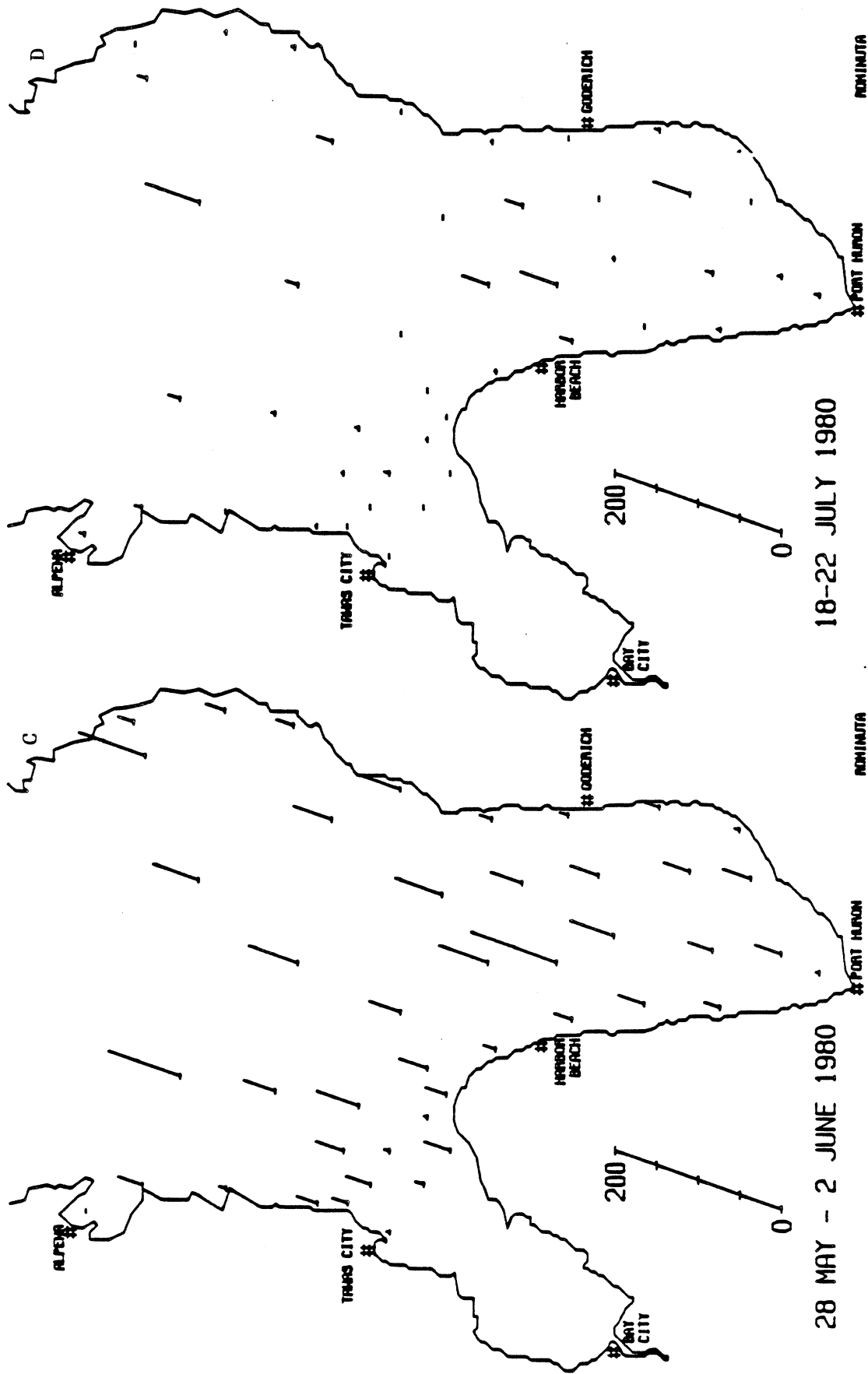


FIG. 60. (continued)

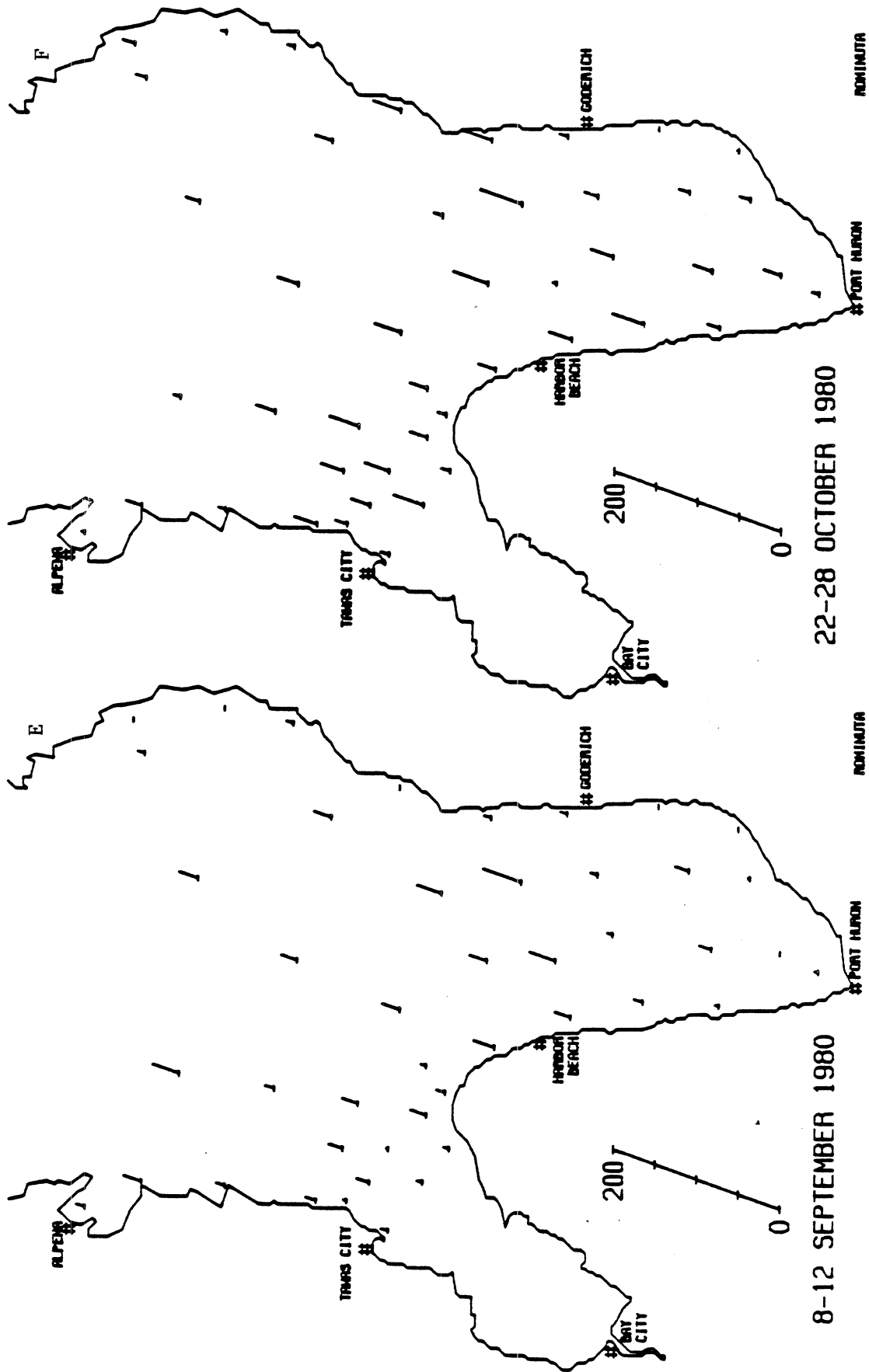


FIG. 60. (continued)

April (Fig. 61A). In May (Fig. 61B), it was widely distributed showing elevated cell numbers compared to April. Greatest abundances were found at nearshore localities near Goderich and the U.S. coastline. Generally, a uniform distribution was seen in June (Fig. 61C). However, this taxon had been substantially reduced near Goderich. During July (Fig. 61D), highest abundances were seen in the offshore waters, particularly in the central basin. In September and October (Figs. 61E and 61F) this form was widely distributed in moderate numbers but was centered primarily in the open lake.

#### Pyrrhophyta - Dinoflagellates

The dinoflagellates usually comprise a relatively small fraction of phytoplankton assemblages in the upper Great Lakes. However, due to the large size of certain species, they may contribute a substantial portion of assemblage biomass. Dinoflagellates typically form blooms in the marine situation, especially those known as the red tide (Sweeney 1976). In the Great Lakes, substantial populations have been observed in Lake Erie, particularly during the spring months (Munawar and Munawar 1976).

In southern Lake Huron, dinoflagellates constituted only a minor portion of the algal assemblage. Dinoflagellates exhibited fairly low abundances in April (Fig. 62A) but occurred throughout the study area. Highest abundances were seen in outer Saginaw Bay and nearshore south of Goderich. Increased abundances were recorded in May (Fig. 62B), particularly in the coastal areas south of Alpena, Saginaw Bay, and Goderich. Largest abundances for the year were recorded in June (Fig. 62C). Greatest abundance was seen at a single station in the mid-southern basin. High abundances were also seen at Alpena, in Saginaw Bay, and the nearshore zone of the northeastern sector. Decreased

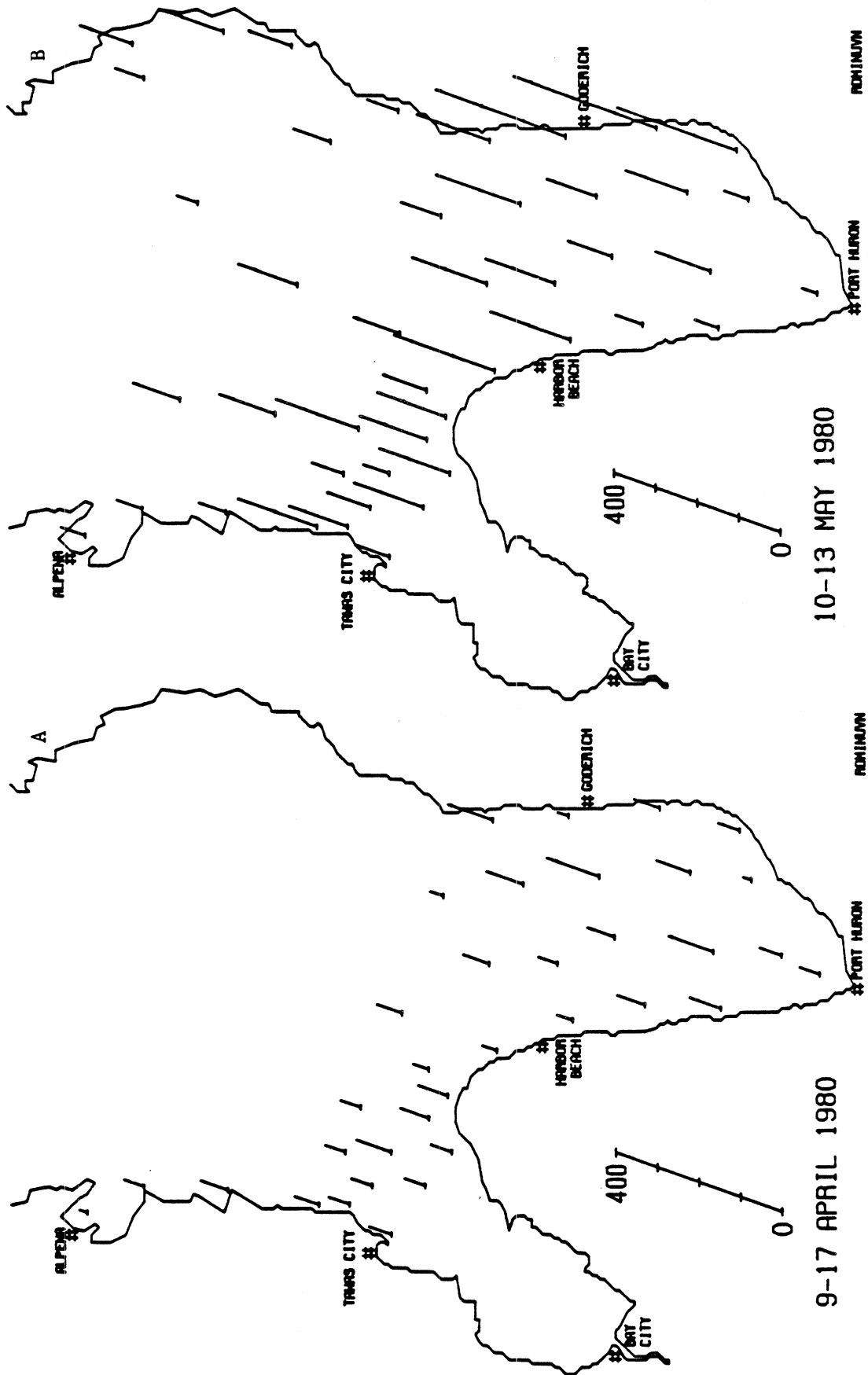


FIG. 61. Distribution of *Rhodomonas minuta* var. *nannoplanctica*.

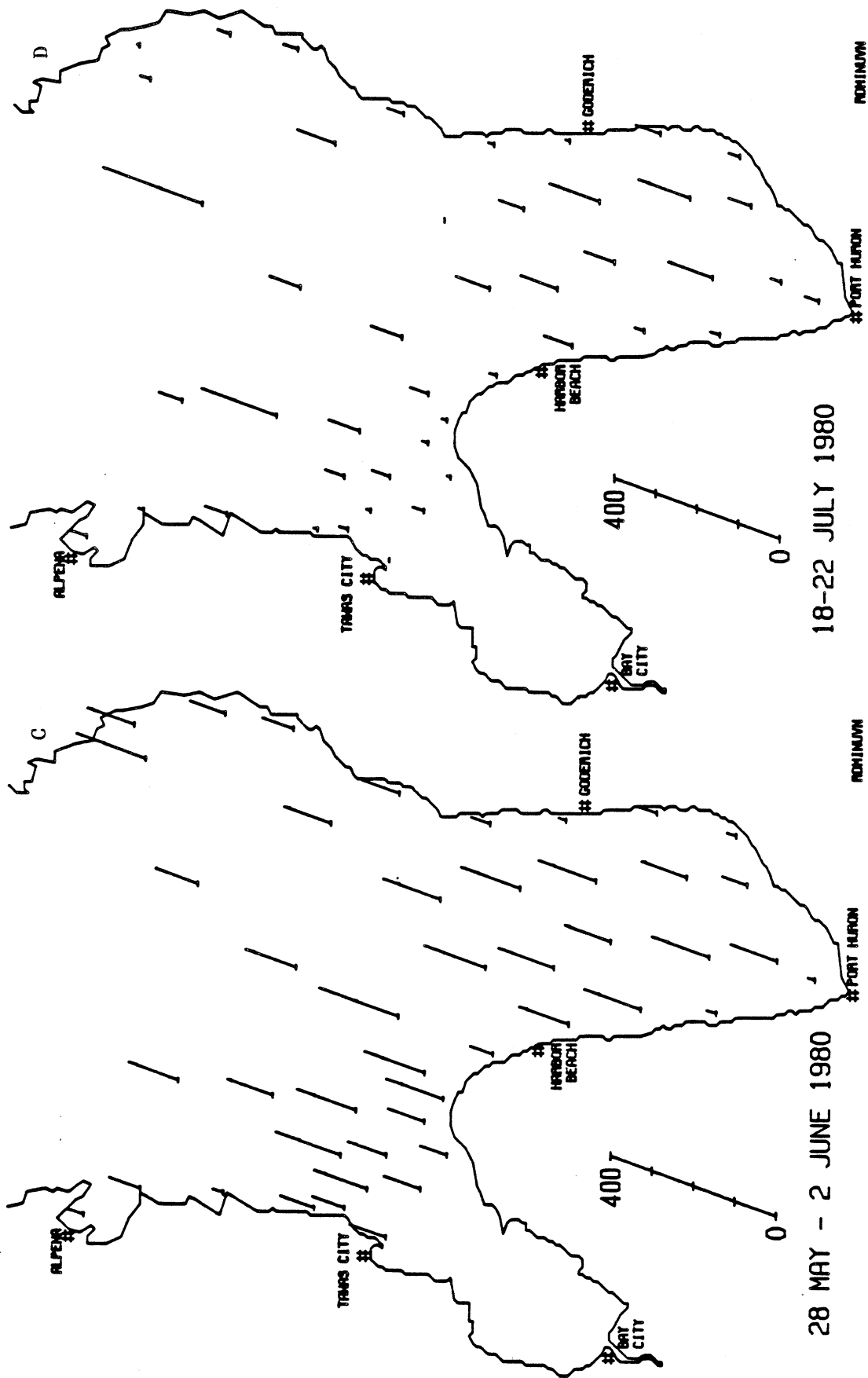


FIG. 61. (continued)

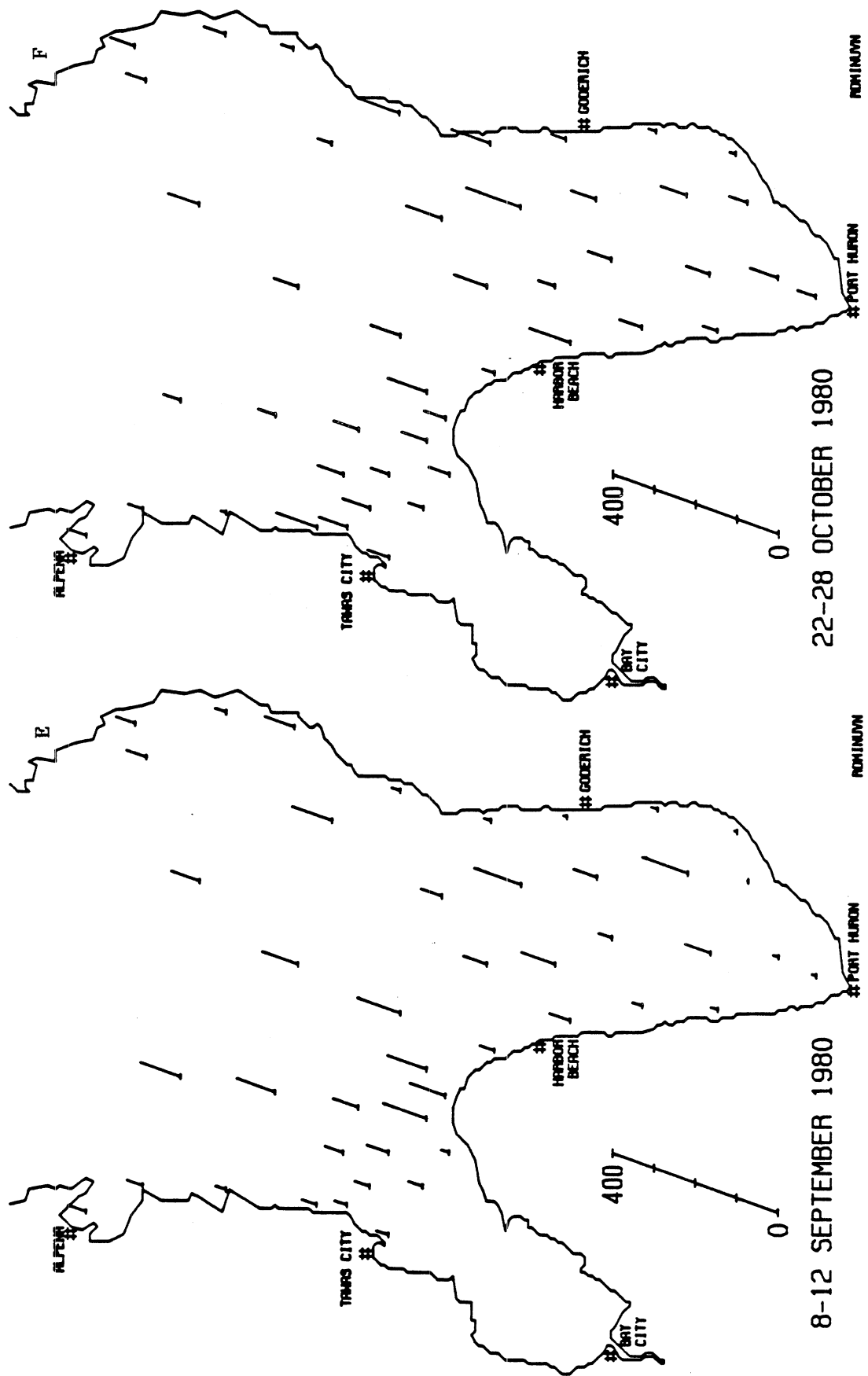


FIG. 61. (continued)

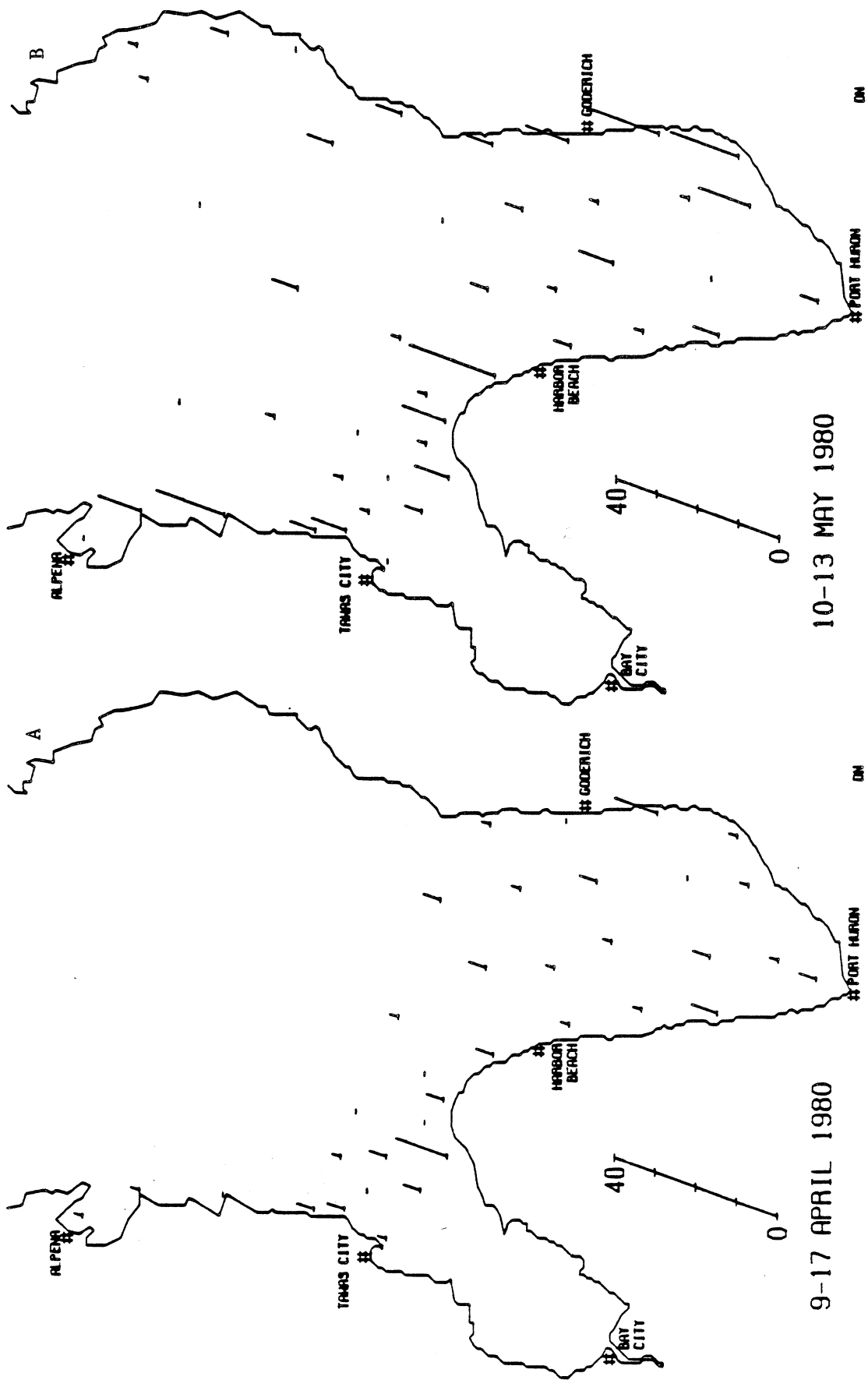


FIG. 62. Seasonal distribution and abundance trends (cells/mL) of dinoflagellates, 1980.

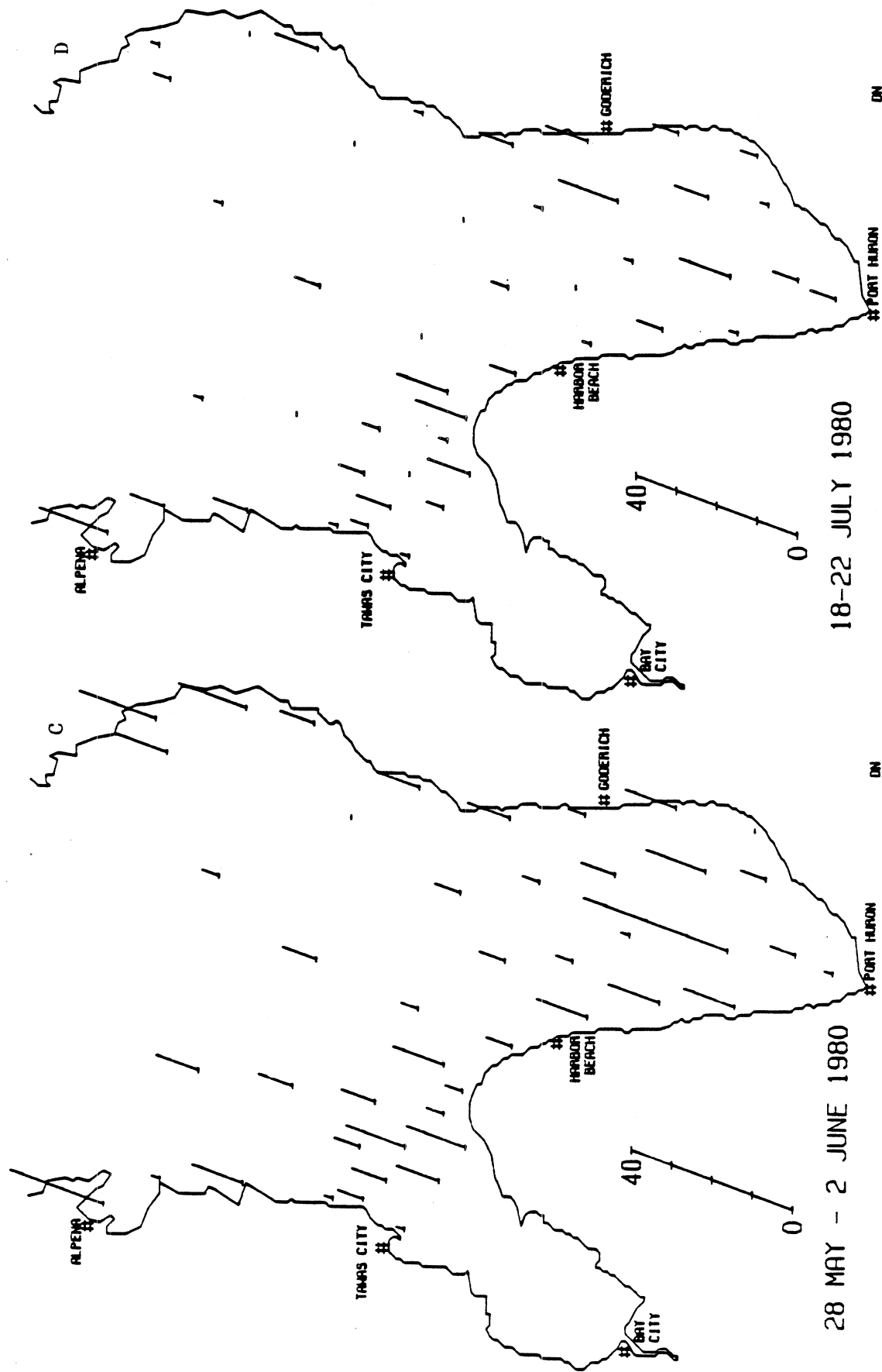


FIG. 62. (continued)

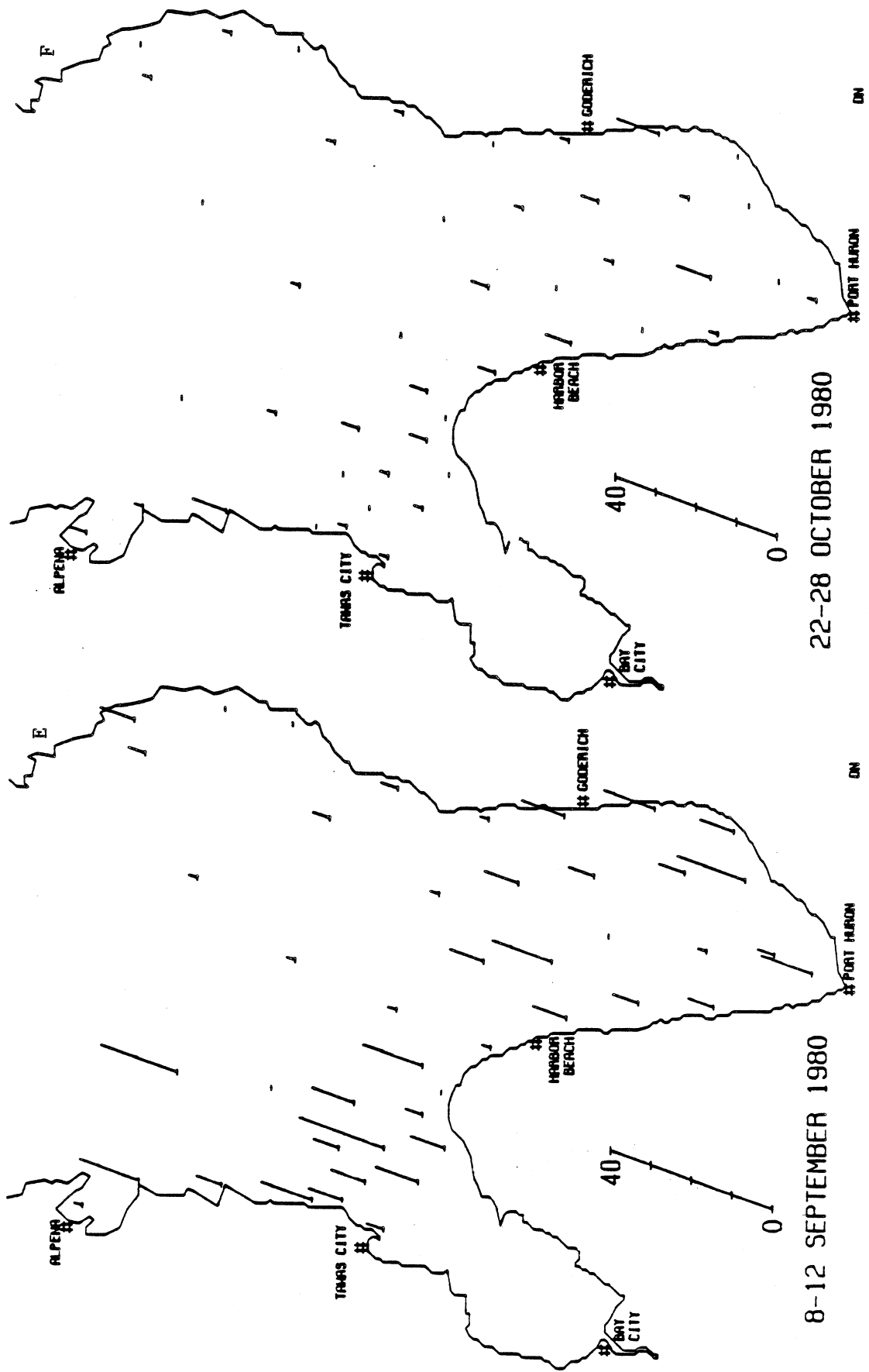


FIG. 62. (continued)

cell numbers were observed in July (Fig. 62D), with highest abundances being noted again at Alpena and in Saginaw Bay. Slightly higher values were recorded in September (Fig. 62E), especially in the Saginaw Bay-Lake Huron interface, but no distinct distributional trend was apparent. Substantially reduced cell densities were observed in October (Fig. 62F) and, although widely distributed, exhibited no distinct pattern.

#### Gymnodinium ordinatum--

This species is a relatively small dinoflagellate whose ecology is unknown for the Great Lakes. It has previously been reported from Lake Huron (Nicholls et al. 1977a) and Lake Superior (Munawar and Munawar 1978) in low abundance. In southern Lake Huron it was distinctly most abundant during the spring months. In April (Fig. 63A), this species reached its widest occurrence and highest average abundance. It was present throughout most of the southern basin. Its greatest abundance was in the nearshore zones of outer Saginaw Bay, south of Goderich and between Harbor Beach and Port Huron. During May (Fig. 63B), reduced occurrences and abundances were observed. Highest cell densities were located south of Saginaw Bay. In June (Fig. 63C), occurrences were observed in the southern basin and in the northeastern sector of the central basin. A large abundance was noted in the mid-southern basin. From July through October (Figs. 63D-63F), standing crops were greatly reduced with isolated occurrences predominantly in the southern basin.

#### SURVEY-WIDE COMPARISONS, 1974 AND 1980

In the following comparisons, the entire data sets for 1974 and 1980 are utilized to assess the status of Lake Huron algal assemblages. Although sampling coverage differed slightly both seasonally and spatially between 1974

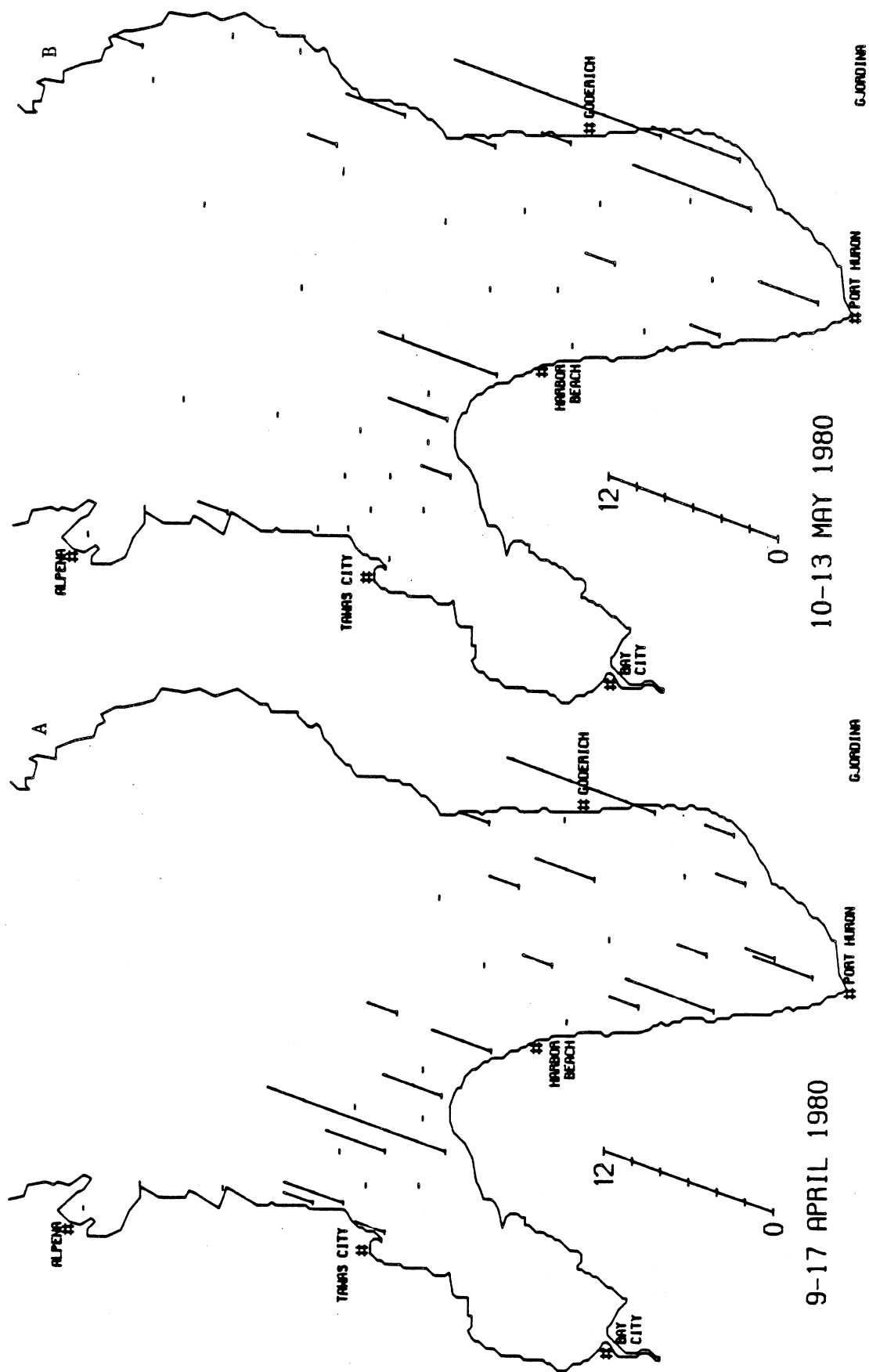


FIG. 63. Distribution of *Gymnodinium ordinatum*.

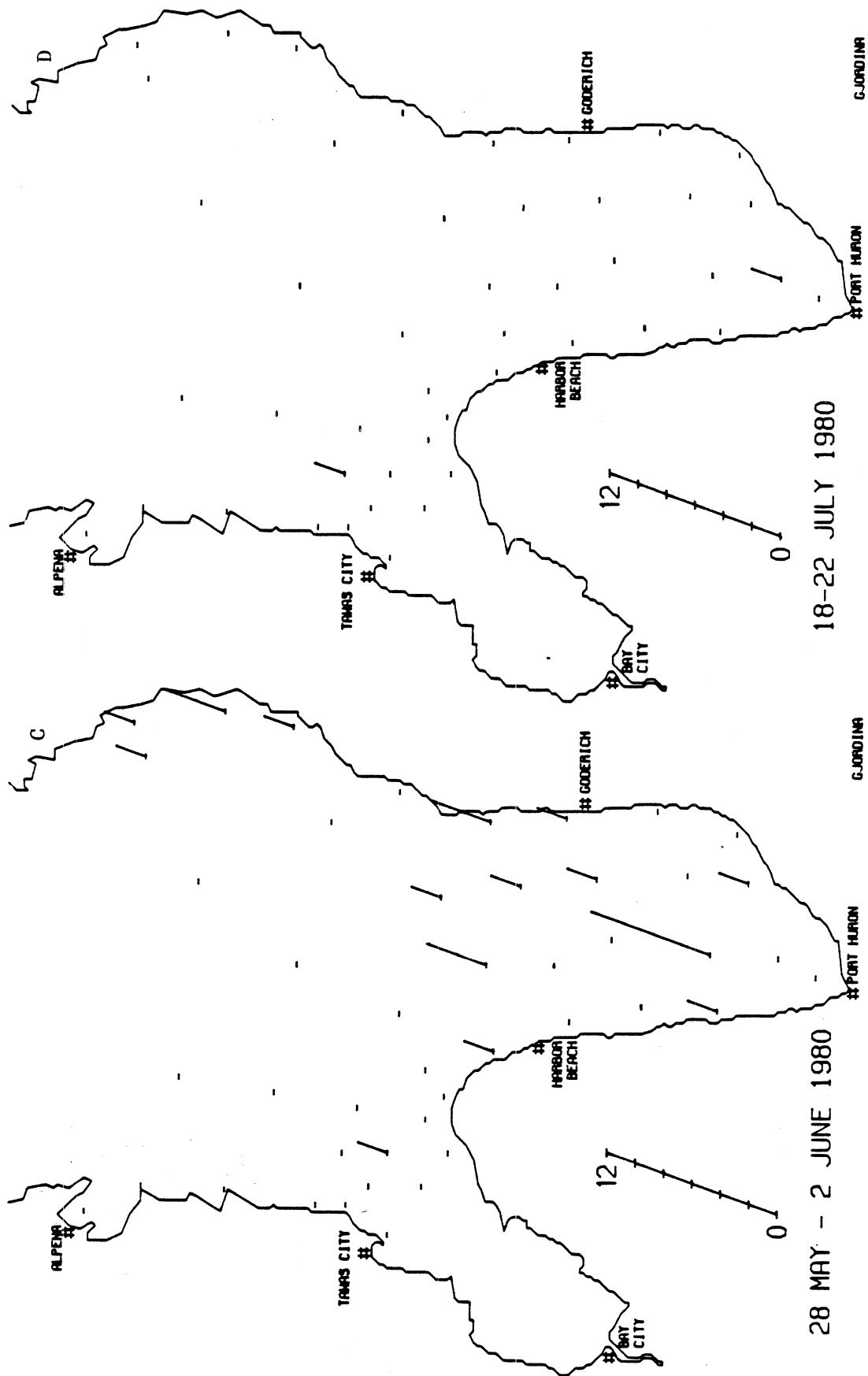


FIG. 63. (continued)

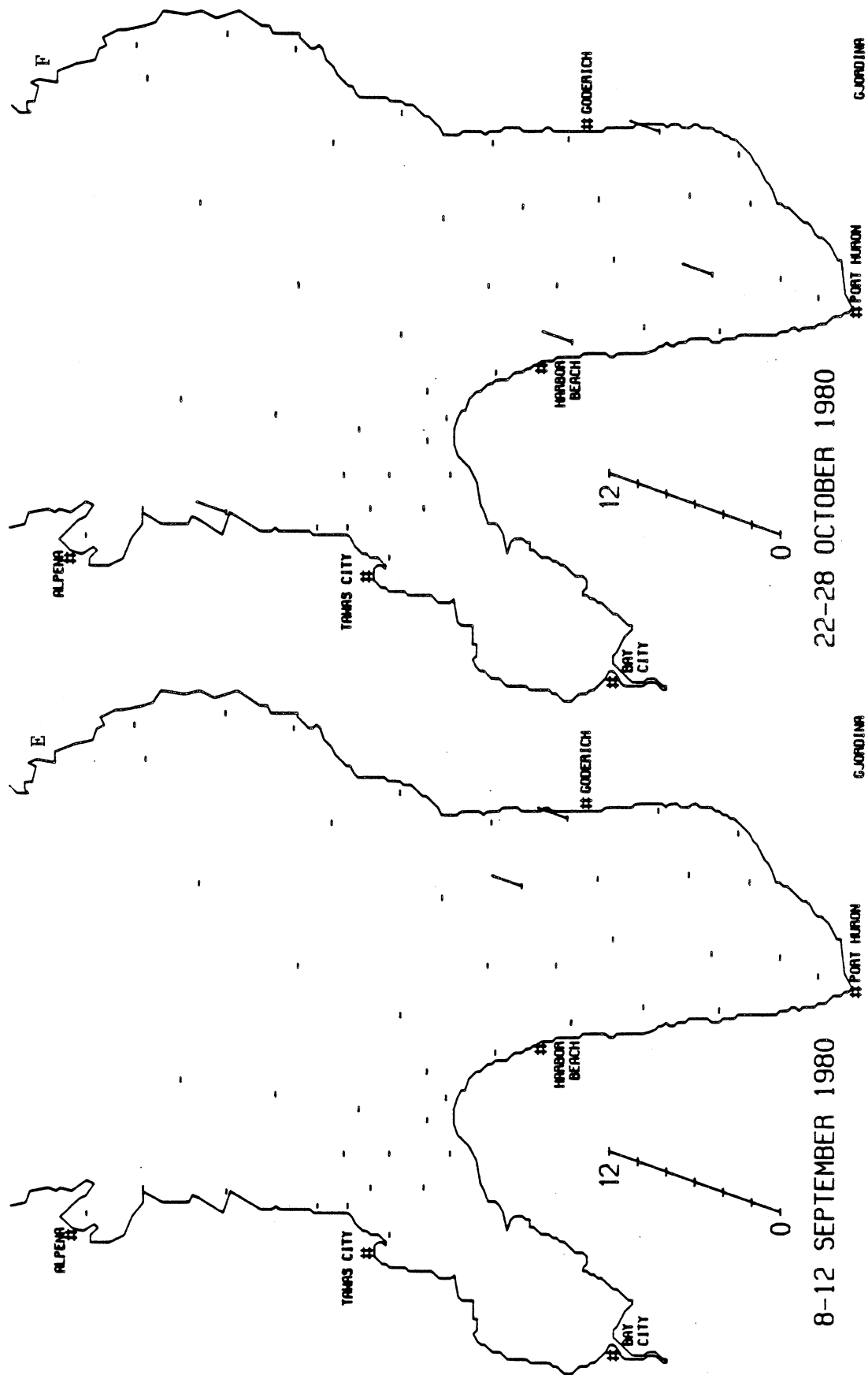


FIG. 63. (continued)

and 1980, these comparisons yield information on the widest areal basis possible. Results of the 1974 southern Lake Huron survey can be found in Stoermer and Kreis (1980). Certain data from the 1974 study are reproduced in the following comparisons.

Two statistical methods have been employed for comparing abundance and distribution differences between 1974 and 1980. Analysis of variance (ANOVA) was utilized to investigate statistical differences in the abundance of total phytoplankton, divisional groups, and individual species between years and monthly sampling periods. Principal component analysis (PCA) was employed to detect differences in algal distribution between cruise seasons. Statistical analyses were accessed through the Michigan Terminal System and the MIDAS statistical package (Fox and Guire 1976).

In 1974, a total of 440 algal species was recorded, whereas in 1980, 382 algal taxa were observed. The difference in species richness is primarily a result of the greater number of samples enumerated for the 1974 cruise season. However, in some instances, certain species that were prevalent or common in 1974 were not observed in 1980. Species richness was lowest during summer and, on average, higher in the fall than during the spring for both years. Conversely, species diversity was highest during the spring in both cases, indicating that even though more taxa were observed in the fall, these assemblages contained certain populations that exerted a strong dominance. Mean species diversity significantly increased ( $p < 0.05$ ) between 1974 and 1980 (Table 25).

Mean algal standing crop in southern Lake Huron was moderate during both years, decreasing from 2,101 cells/mL in 1974 to 1,881 cells/mL in 1980 (Table 25). However, the difference was not statistically significant ( $p < 0.05$ ). A

TABLE 25. Summary of southern Lake Huron phytoplankton for all cruises and stations at 5 meters, 1974 and 1980.

	1974		1980	
Average (cells/mL)	2,101		1,881	
Range (cells/mL)	293-38,220		222-6,272	
Standard deviation	3,165		997	
Mean diversity	2.292		2.389	
	Mean Relative Abundance (%)		Mean Absolute Abundance (cells/mL)	
	1974	1980	1974	1980
Blue-greens	18.15	21.99	381.3	413.6
Greens	36.99	5.14	777.0	96.6
Diatoms	37.63	34.50	790.5	649.0
Chrysophytes	3.61	10.64	75.7	200.1
Cryptomonads	0.78	7.54	16.3	141.7
Dinoflagellates	0.06	0.28	1.31	5.3
Euglenoids	<0.01	<0.01	0.03	0.01
Undetermined	2.77	19.85	58.1	373.4

range in standing crop, encompassing two orders of magnitude with an accompanying high standard deviation, was observed in 1974 (Table 25). The abundance range decreased to one order of magnitude with a lower standard deviation in 1980 (Table 25). The wide ranges suggest that regions within the study area differ greatly from one another.

Dramatic differences in absolute and relative abundances of the major algal divisions were observed between 1974 and 1980 (Table 25). Diatoms were the dominant algal group during both years, although green algae co-dominated in 1974. Diatoms and greens were the only major physiological groups to show significant decreases ( $p < 0.05$ ) between the two years. Diatom abundance was moderately lower in 1980, whereas green algae decreased by 32%. All other major algal divisions showed higher cell densities in 1980. Blue-green algae showed slightly higher densities in 1980, but the difference was not statistically significant ( $p < 0.05$ ). Chrysophytes, cryptomonads, and the undetermined category significantly increased ( $p < 0.05$ ). Typically, dinoflagellates and euglenoids constitute a minor portion of assemblages observed and negligible changes were recorded.

#### COMPARISON OF SEASONAL ABUNDANCE TRENDS OF TOTAL PHYTOPLANKTON AND THE MAJOR ALGAL GROUPS, 1974 AND 1980

Seasonal abundance of total phytoplankton for April through November 1974 and April through October 1980 are presented in Tables 26 and 27, respectively, and in Figure 64. Bimodal seasonal patterns were observed during both years for total abundance (Fig. 64), however, several major differences are apparent between the five monthly sampling periods that could be compared. Highest abundances for each respective sampling period were observed in the spring for 1980 and during the fall in 1974 (Fig. 64). The

TABLE 26. Seasonal means of total phytoplankton and major algal groups (cells/mL) at 5 meters, southern Lake Huron, cruises 1-8, 1974.

GROUP	CRUISE							
	1	2	3	4	5	6	7	8
Total	1,037.6	1,821.7	1,994.0	1,382.4	1,901.2	2,281.5	3,693.1	2,499.6
Blue-greens	1.4	49.9	88.2	153.6	154.4	529.4	1,329.8	683.0
Greens	109.8	435.8	740.6	280.9	1,255.2	807.8	1,355.9	997.8
Diatoms	813.1	1,224.3	948.3	875.7	372.6	715.0	770.7	718.5
Chrysophytes	42.7	51.2	61.1	26.3	53.7	166.6	169.8	26.4
Cryptomonads	18.9	20.4	19.4	28.5	9.0	11.8	12.5	11.6
Euglenoids	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Dinoflagellates	2.5	1.4	2.8	0.5	1.2	1.4	0.5	0.5
Undetermined	48.8	38.1	133.4	16.9	55.2	49.4	53.7	61.9

TABLE 27. Seasonal means of total phytoplankton and major algal groups (cells/mL) at 5 meters, southern Lake Huron, cruises 1-6, 1980. This table, a duplicate of Table 6, is placed here for ease of comparison with Table 26.

GROUP	CRUISE					
	1	2	3	4	5	6
Total	2,400.2	1,905.7	1,639.7	1,100.2	2,190.4	2,166.7
Blue-greens	177.5	150.6	202.6	21.7	994.2	876.9
Greens	72.4	112.0	88.5	73.4	123.6	105.1
Diatoms	696.4	596.0	651.9	621.9	585.1	752.3
Chrysophytes	363.9	336.3	168.1	52.0	159.2	160.9
Cryptomonads	151.2	266.3	164.2	83.3	89.5	101.0
Euglenoids	0.0	0.0	0.0	0.0	0.1	0.0
Dinoflagellates	3.0	5.2	8.9	5.3	7.0	2.2
Undetermined	930.4	437.2	355.4	242.6	231.8	168.3

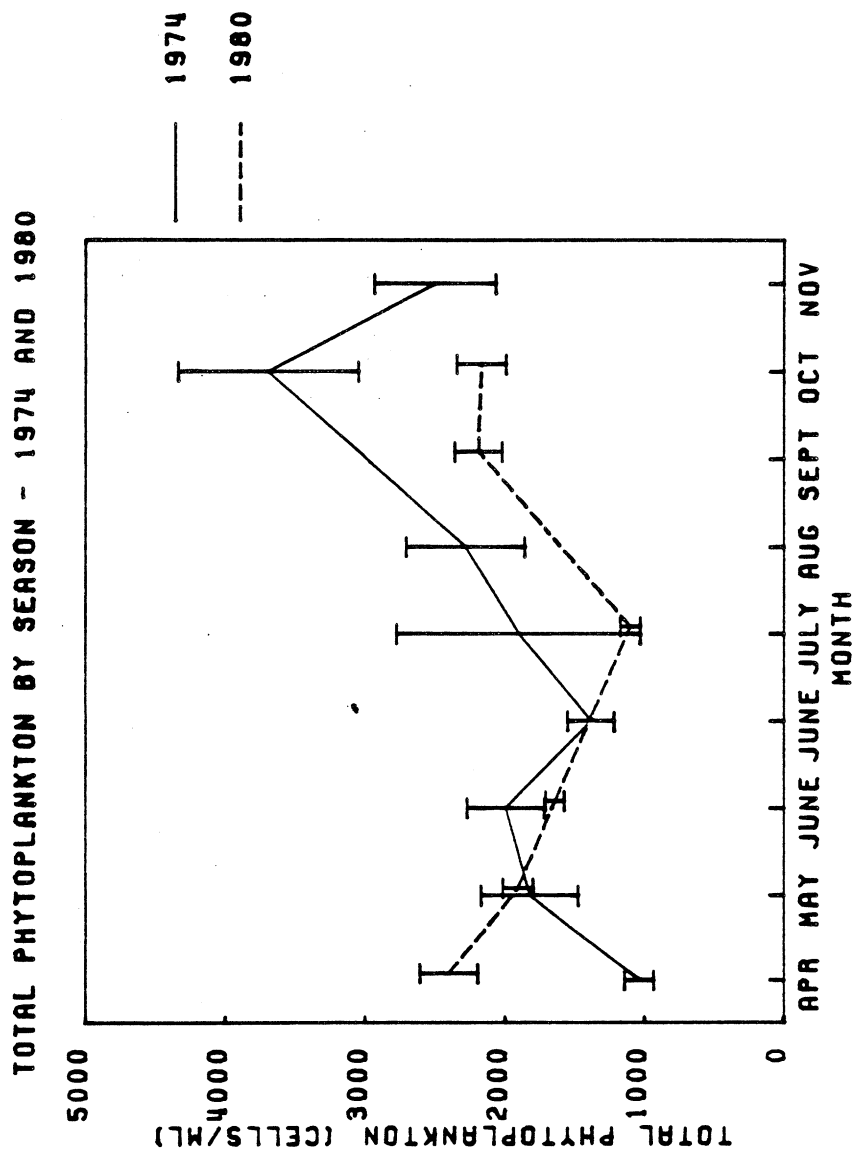


FIG. 64. Southern Lake Huron total phytoplankton (cells/mL) by season, 1974 and 1980. Error bars =  $\pm$  one standard error.

spring peak was observed in April 1980 and showed a significant increase ( $p < 0.05$ ) compared to April 1974. Comparable values were obtained for May and June of both years. In 1980, algal densities decreased through July when the summer minimum was observed (Fig. 64). The summer minimum was observed in late June in 1974. Higher mean values were obtained in July 1974 than in July 1980, but the difference was not statistically significant ( $p < 0.05$ ). High standing crops were observed in the fall months for both years but a significant decrease ( $p < 0.05$ ) was recorded for October 1980 (Fig. 64).

Mean seasonal abundances of the major physiological groups are presented in Tables 26 and 27 for 1974 and 1980, respectively. Greatest concentrations of blue-greens were recorded during the fall sampling periods. Comparatively higher blue-green abundance was observed in the spring of 1980 and showed significant increases ( $p < 0.05$ ) in April and May compared to 1974. However, blue-greens were significantly reduced ( $p < 0.05$ ) in July and October 1980, as opposed to the same months in 1974. Green algae exhibited highest mean values during the summer and fall of both years (Tables 26 and 27). Green algae were consistently lower through all sampling periods in 1980 and significant decreases ( $p < 0.05$ ) were observed for June and October 1980. Diatom abundance was consistent and showed little seasonal variation during either year, but slightly higher values were recorded for the spring, as compared to the fall, of 1974. Diatom abundance showed significant decreases ( $p < 0.05$ ) for May and June between 1974 and 1980 and a significant increase ( $p < 0.05$ ) was observed in July 1980. Chrysophytes showed distinctly different seasonal patterns between the two years (Tables 26 and 27). In 1974, chrysophytes were most abundant during the fall months, whereas in 1980, highest abundances were recorded during the spring. Chrysophytes significantly increased ( $p < 0.05$ ) during the

spring months of 1980, compared to those of 1974. Cryptomonads, dinoflagellates, and undetermined microflagellates all significantly increased ( $p < 0.05$ ) between 1974 and 1980 in at least three of the five months that could be statistically analyzed.

#### COMPARISON OF SEASONAL DISTRIBUTION AND ABUNDANCE TRENDS OF TOTAL PHYTOPLANKTON AND THE MAJOR ALGAL GROUPS, 1974 AND 1980

For these comparisons, certain data are reproduced from the 1974 and 1980 surveys for inspection of general trends. The reader should refer to Stoermer and Kreis (1980) for a complete account of the 1974 data and earlier discussions in this report for a complete account of the 1980 data. Note that the abundance scales (cells/mL) may differ between years in some of the monthly comparisons due to abundances encountered.

During the spring months of each year, higher standing crops were typically observed at nearshore stations, apparently due to spring thermal bar conditions. However, it should be noted that during most sampling periods phytoplankton abundance in southern Lake Huron was numerically dominated by the extremely high cell densities in outer Saginaw Bay. This condition is evident more so in 1974 than during 1980.

During April 1974, phytoplankton standing crop was low and uniform with slightly higher abundances at locations in nearshore zones north of East Tawas and around the southern basin. Higher mean values were recorded in April 1980 than in 1974, and were the highest recorded for the 1980 cruise season, as previously discussed. In April 1980, high cell densities were seen along the entire U.S. shoreline and in the Saginaw Bay interface waters, but particularly in the nearshore zone between Alpena and Tawas. During May of both years (Figs. 65A and 65B), high standing crops were observed in outer

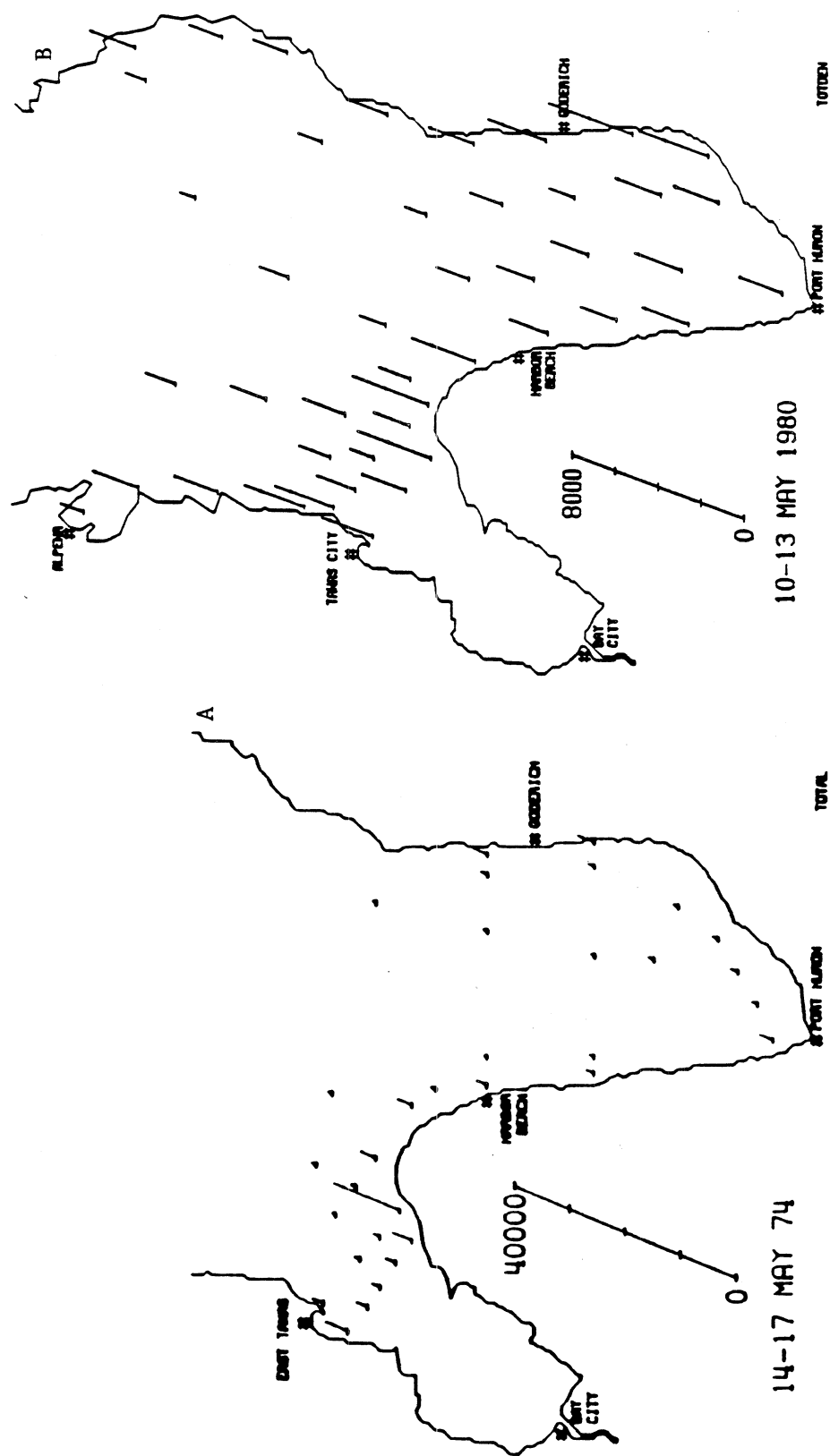


FIG. 65. Distribution and abundance (cells/mL) of total phytoplankton, May 1974 (A) and 1980 (B).

Saginaw Bay extending southward around the thumb area of Michigan. High abundances were also observed in the Canadian nearshore zone near Goderich for both years.

During both June cruises in 1974, highest cell densities were centered in Saginaw Bay extending southward along the U.S. coastal area. Standing crops in the offshore waters were uniform during both months but were distinctly lower than those observed in outer Saginaw Bay. In June 1980, total standing crop was evenly distributed throughout the study area with slightly elevated abundances in Thunder Bay at Alpena, the Saginaw Bay interface waters, and a few nearshore localities along the Canadian coast.

Extremely high standing crops were recorded in southeastern Saginaw Bay during July 1974 (Fig. 66A). In July 1980, a summer minimum was observed (Fig. 66B) and much lower abundances were observed in Saginaw Bay compared to July 1974. Highest cell concentrations were found in the Saginaw Bay interface waters with lower abundances observed at offshore stations during both years.

During October and November 1974, the same general distribution pattern for phytoplankton standing crop was observed (Fig. 67A). Highest abundances were centered in outer Saginaw Bay and southward along the U.S. shoreline. These months also had the highest mean standing crops observed for the cruise season and were substantially higher than any mean values recorded for 1980. Samples during October 1980 revealed high standing crops along the entire U.S. sector of the study area including Saginaw Bay and adjacent waters (Fig. 67B).

Blue-green algae generally exhibited highest cell concentrations during the fall months of both years. During the spring months of 1974, extremely low blue-green densities were observed throughout the study area, e.g., May

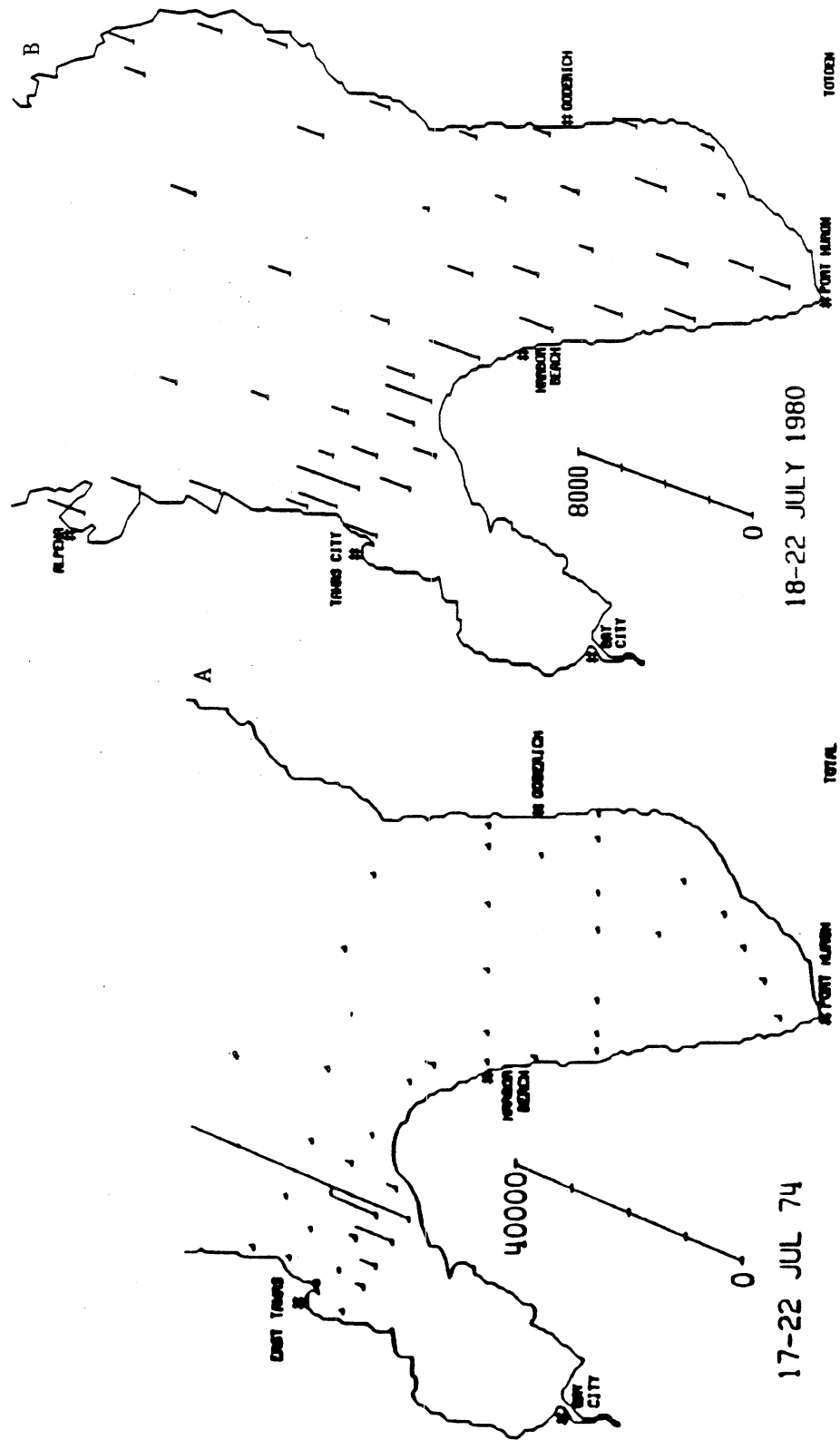


FIG. 66. Distribution and abundance (cells/mL) of total phytoplankton, July 1974 (A) and 1980 (B).



(Fig. 68A). When blue-greens were present, they were generally observed in outer Saginaw Bay. However, in the spring of 1980, blue-green algae occurred throughout the study area (Fig. 68B) and were considerably more abundant than in 1974. During July 1974, moderately high blue-green abundances were restricted to outer Saginaw Bay and southward (Fig. 69A). Comparatively very low blue-green numbers were observed in July 1980 (Fig. 69B), with occurrences primarily in the Saginaw Bay interface and the central basin.

Blue-green algae attained their greatest abundance of any sampling period for either year in October, 1974 (Fig. 70A). Blue-green densities were greatest in Saginaw Bay, extending southward into the mid-southern basin. During October 1980, blue-greens were widely distributed throughout the study area in moderate numbers (Fig. 70B). Comparatively, blue-greens were less prevalent in October 1980 than in October 1974.

Typically, low standing crops of green algae were observed during the spring months of both years. However, concentrations were consistently higher in 1974, as compared to 1980. In the spring and early summer of 1974, the distribution of green algae was dominated by moderate abundances found in outer Saginaw Bay with scattered occurrences over the remainder of the study area (Fig. 71A). During the 1980 spring period, greens were widely distributed in no apparent pattern (Figs. 71B) but at comparatively lower densities than in 1974. In July of both years, the distribution of green algae appeared to be predominantly confined to outer Saginaw Bay and adjacent waters (Figs. 72A and B). During October and November 1974, green algae were generally restricted to outer Saginaw Bay and southward along the U.S. coastline (Fig. 73A). This pattern was also observed in October 1980 (Fig. 73B), but

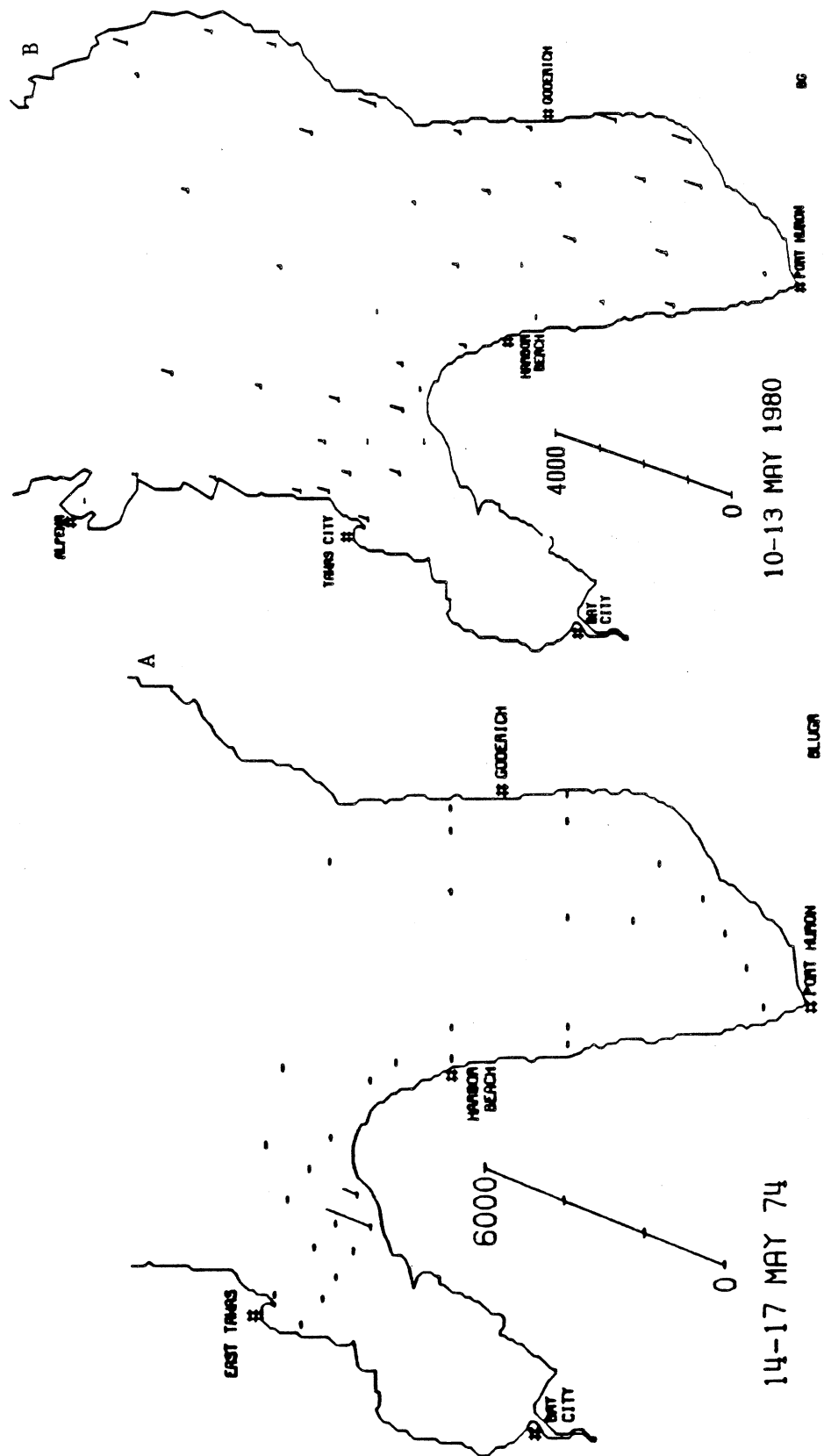


FIG. 68. Distribution and abundance (cells/mL) of blue-green algae, May 1974 (A) and 1980 (B).

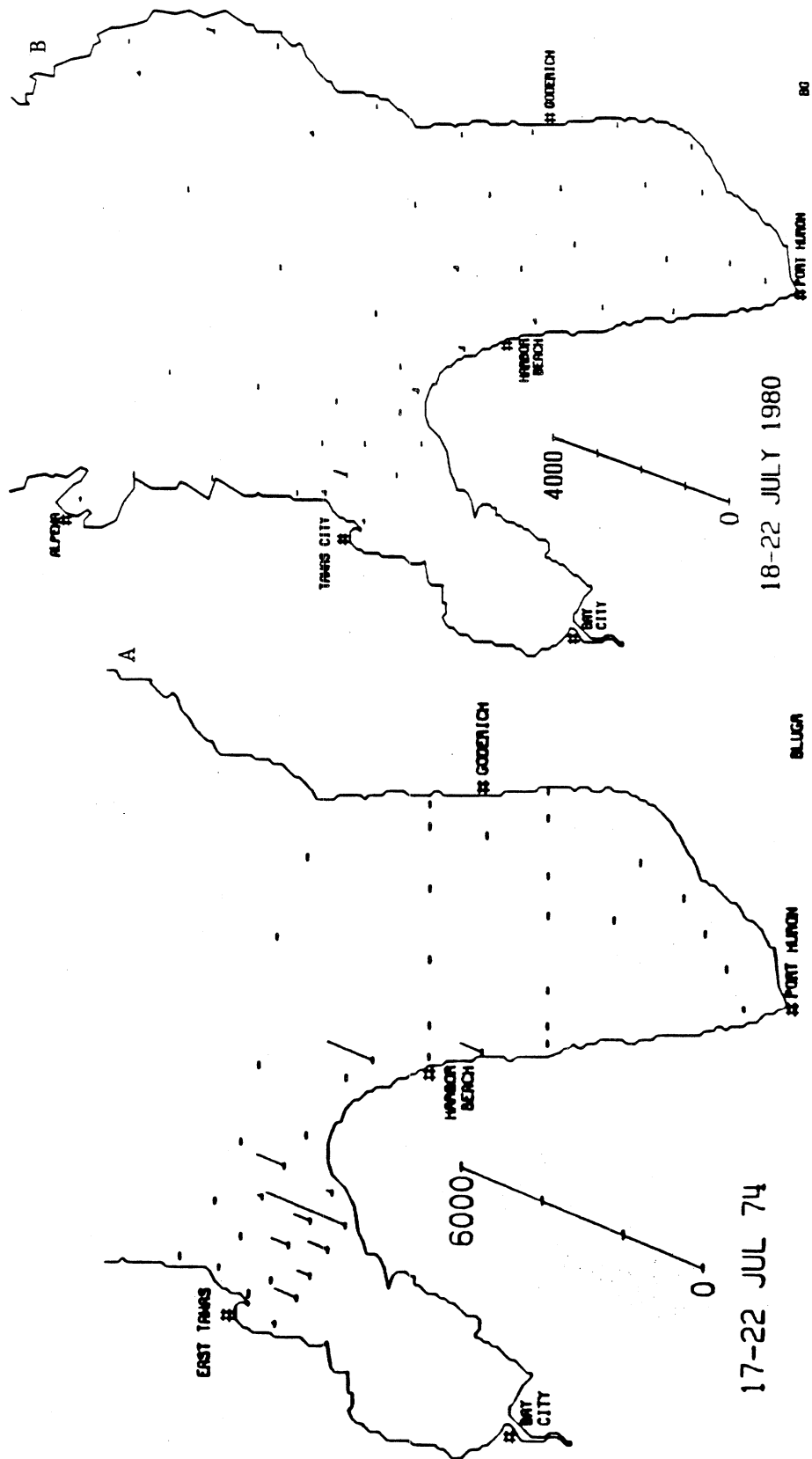


FIG. 69. Distribution and abundance (cells/mL) of blue-green algae, July 1974 (A) and 1980 (B).

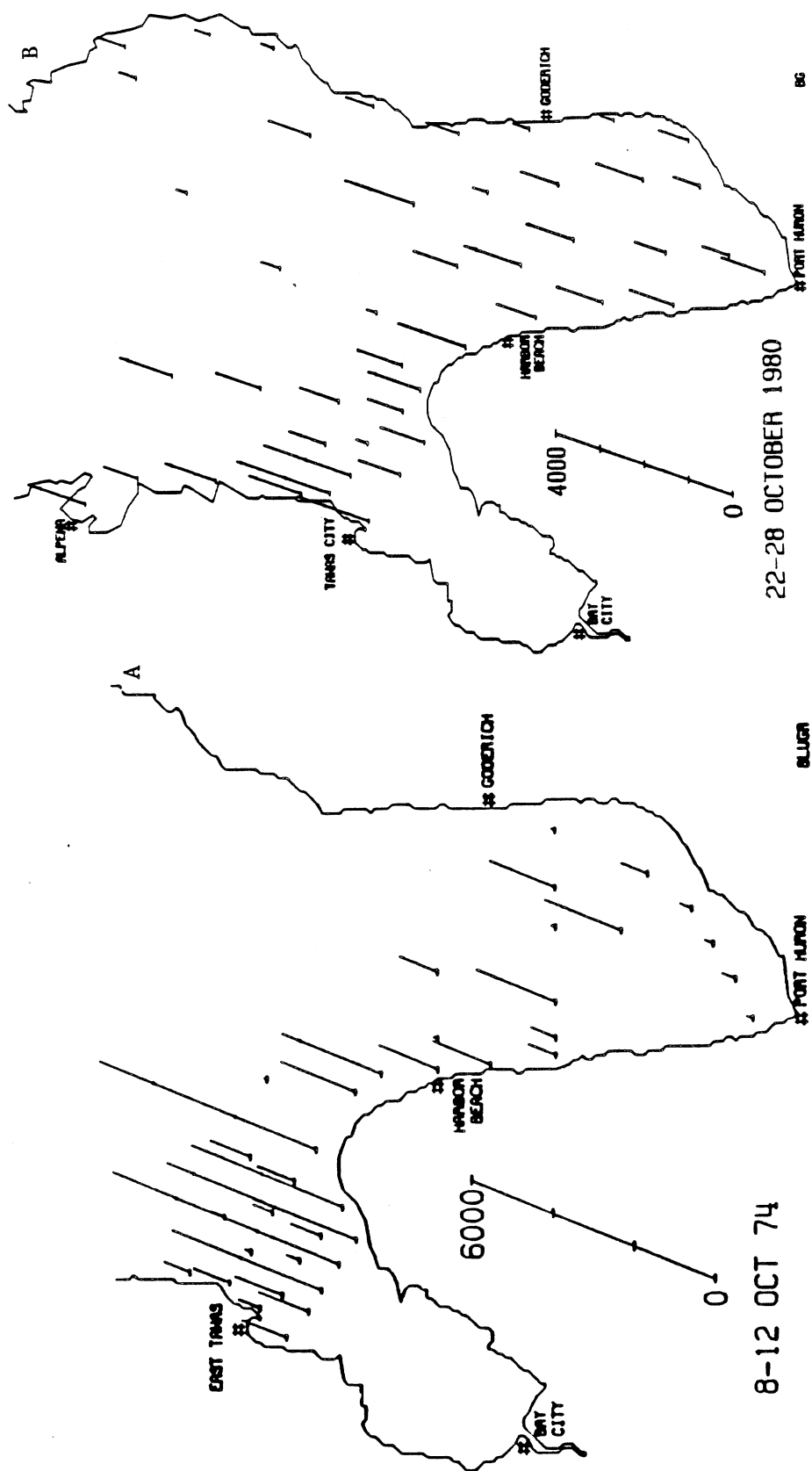


FIG. 70. Distribution and abundance (cells/mL) of blue-green algae, October 1974 (A) and 1980 (B).

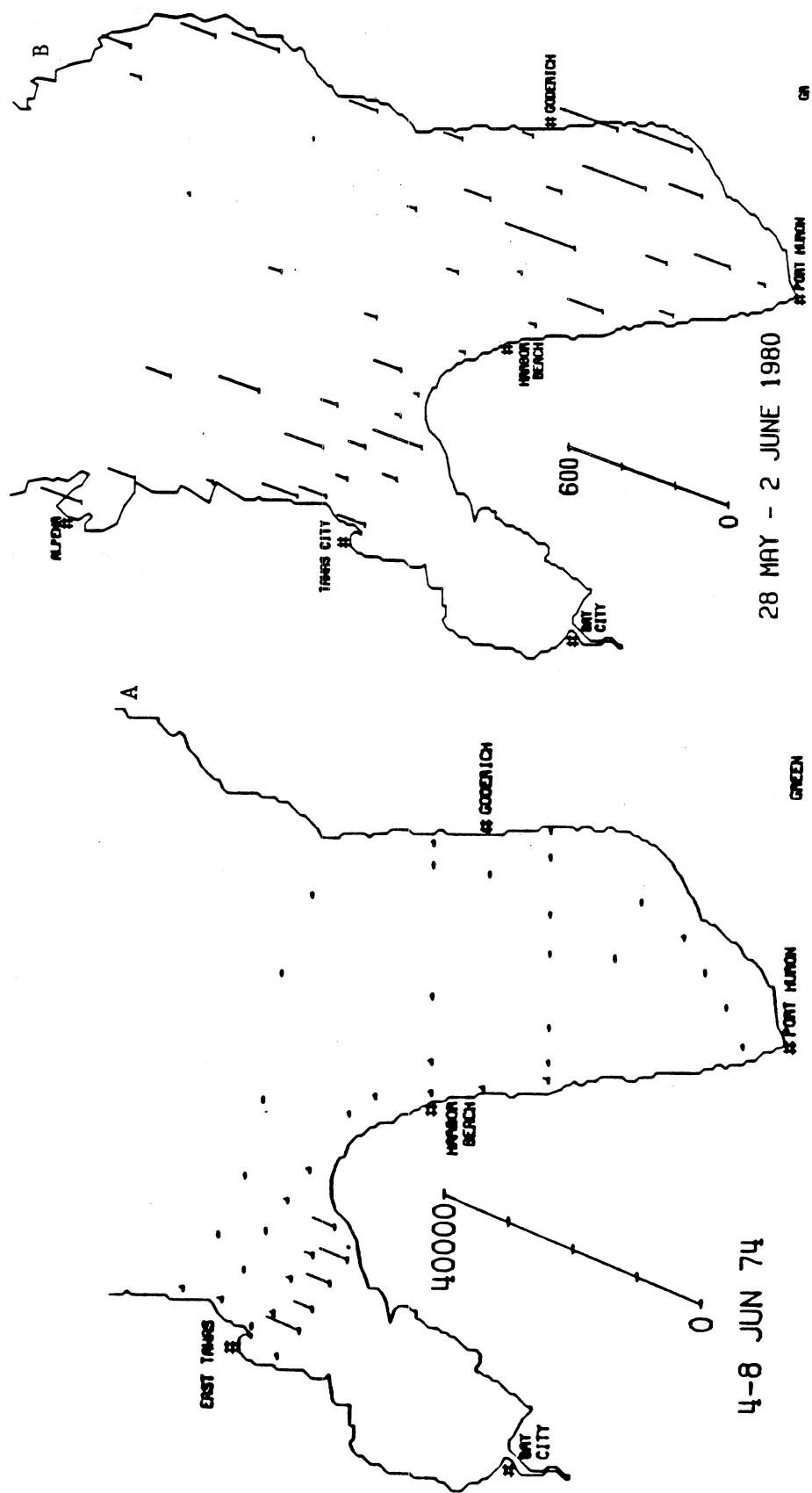


FIG. 71. Distribution and abundance (cells/mL) of green algae, June 1974 (A) and 1980 (B).

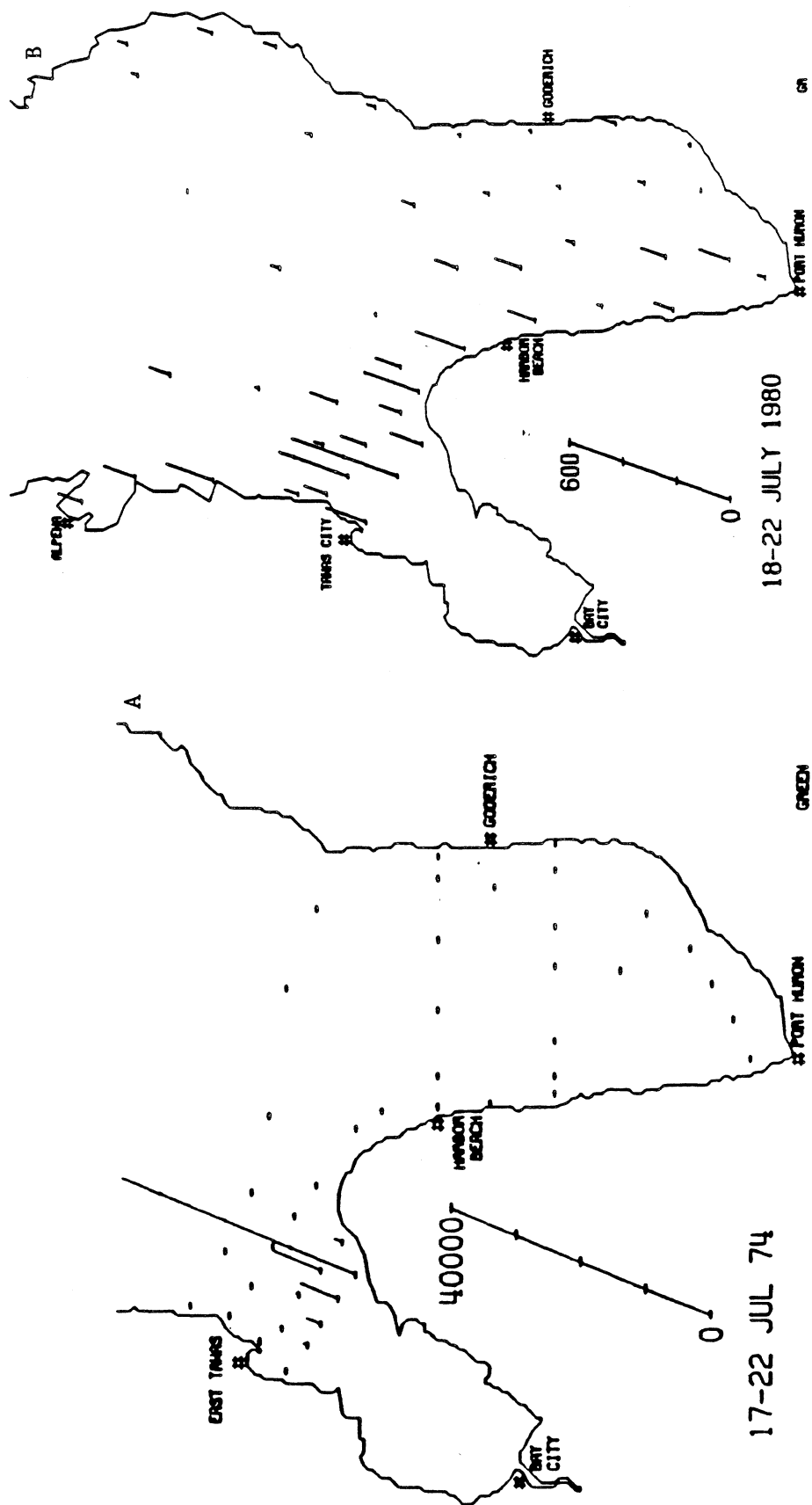


FIG. 72. Distribution and abundance (cells/mL) of green algae, July 1974 (A) and 1980 (B).

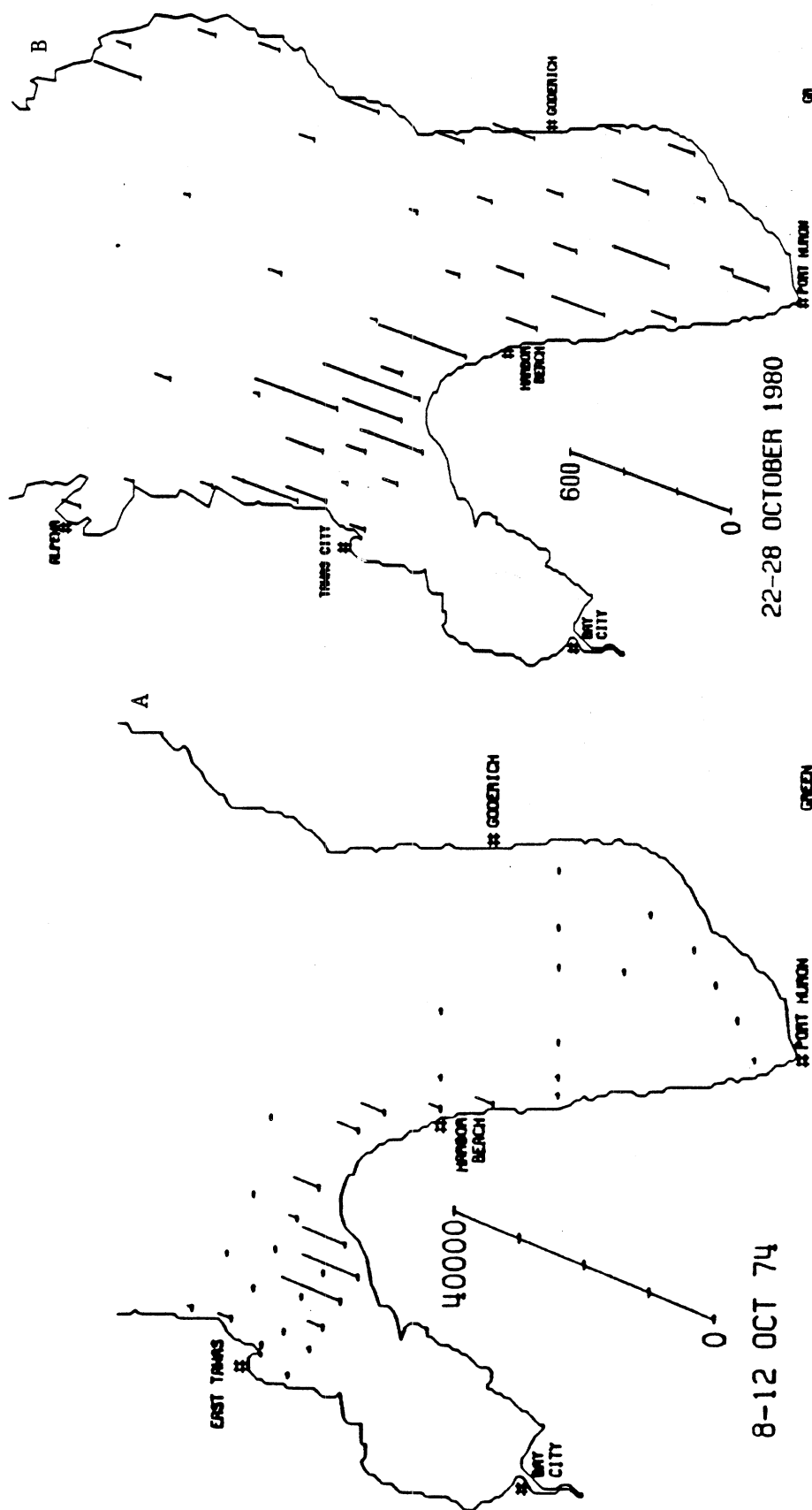


FIG. 73. Distribution and abundance (cells/mL) of green algae, October 1974 (A) and 1980 (B).

with comparatively lower densities in the Canadian sector and the offshore waters of the central basin.

Diatoms had the widest occurrence of the major physiological groups and were always present at every station sampled. During May of both years, diatom standing crops were greatest in the nearshore zones of the study area (Figs. 74A and B). In June 1974, nearshore zones still supported the largest diatom standing crops but the nearshore-offshore difference was not as pronounced. Highest abundances were seen in the U.S. portion of the lake, with large numbers in outer Saginaw Bay and the interface region. Comparatively, diatom abundance was uniform in June 1980 with only slightly elevated densities observed in nearshore zones.

During July 1974, distinctly lower diatom concentrations occurred in the Saginaw Bay interface region and southward as compared to the Canadian half of the lake and the northernmost transect across the lower central basin (Fig. 75A). Conversely, diatom abundance was greatest in the U.S. sector of the lake in July 1980 (Fig. 75B), including the Saginaw Bay interface and southward. During October 1974, abundances were highest in outer Saginaw Bay and in the mid-southern basin nearshore stations (Fig. 76A). Diatom standing crop was highest along the entire U.S. coastline in October 1980 (Fig. 76B), with the Canadian sector of the lake and the offshore zone of the central basin showing much lower densities.

During April 1974 and 1980, high flagellate densities were observed in the northern interface waters of Saginaw Bay (Figs. 77A and B). However, during 1980 very high abundances were seen in the the nearshore zone north of Tawas City. During May 1974, highest concentrations of microflagellates were observed in outer Saginaw Bay and southward (Fig. 78A). High abundances were

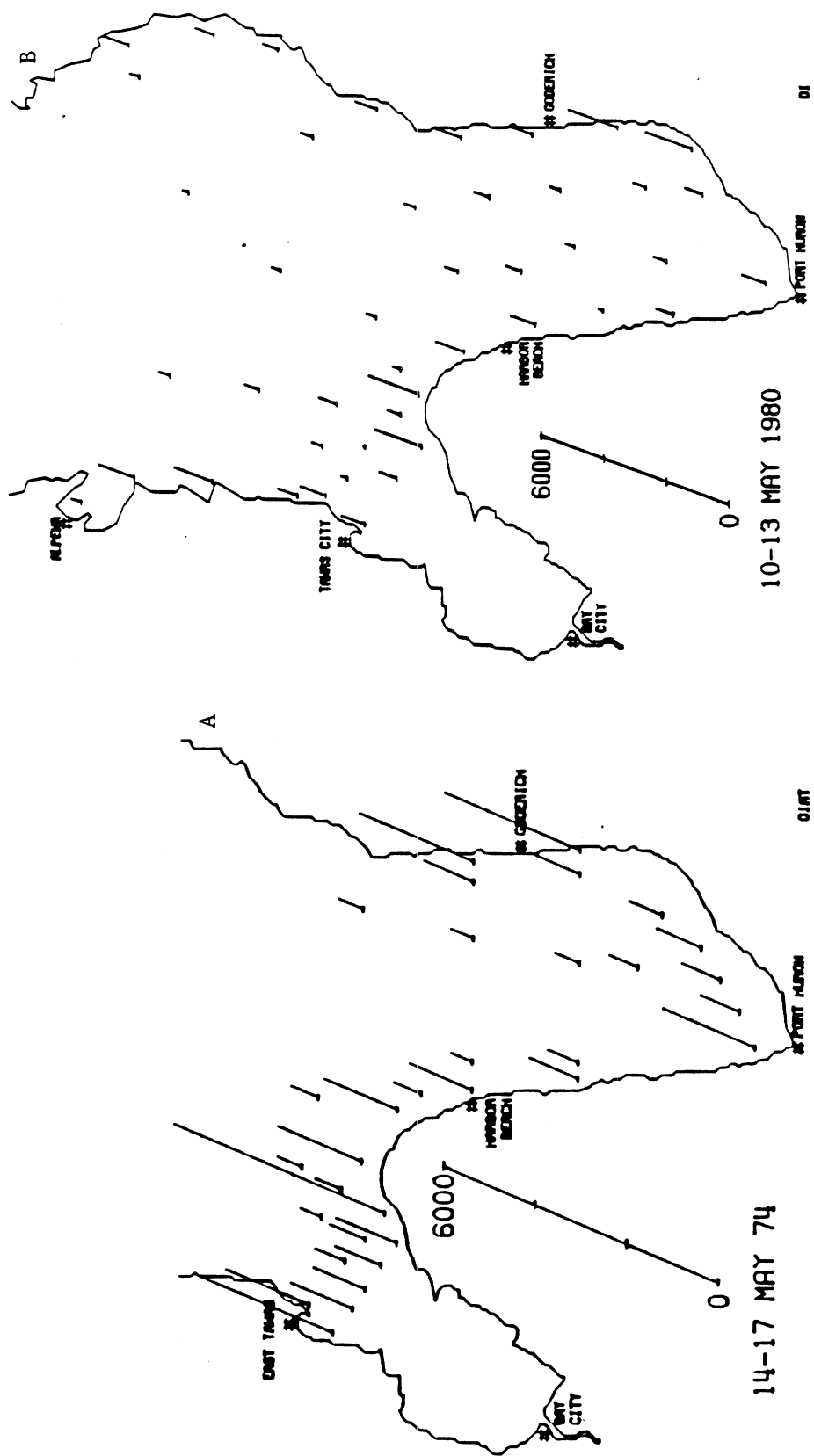


FIG. 74. Distribution and abundance (cells/mL) of diatoms, May 1974 (A) and 1980 (B).

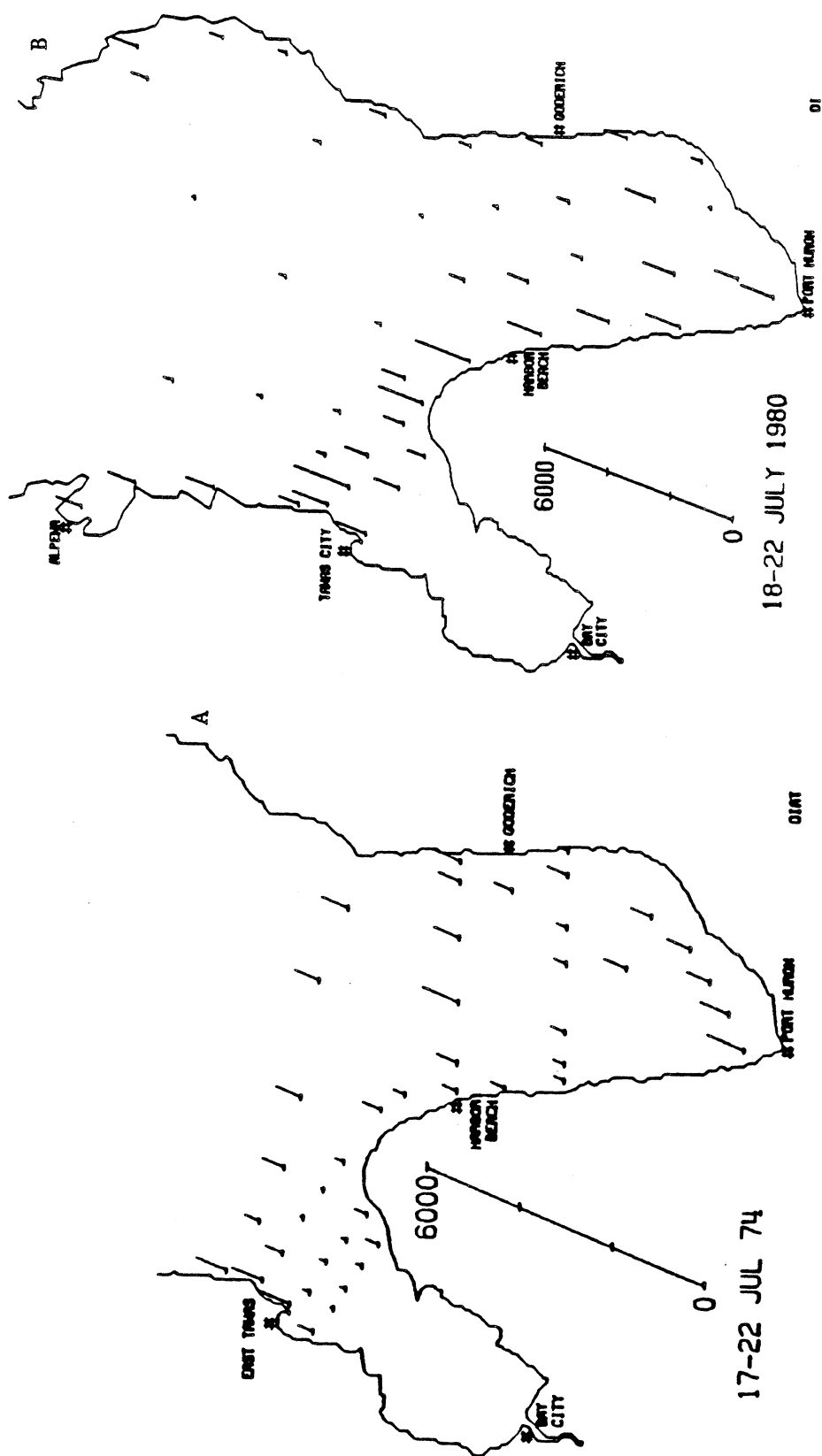


FIG. 75. Distribution and abundance (cells/mL) of diatoms, July 1974 (A) and 1980 (B).

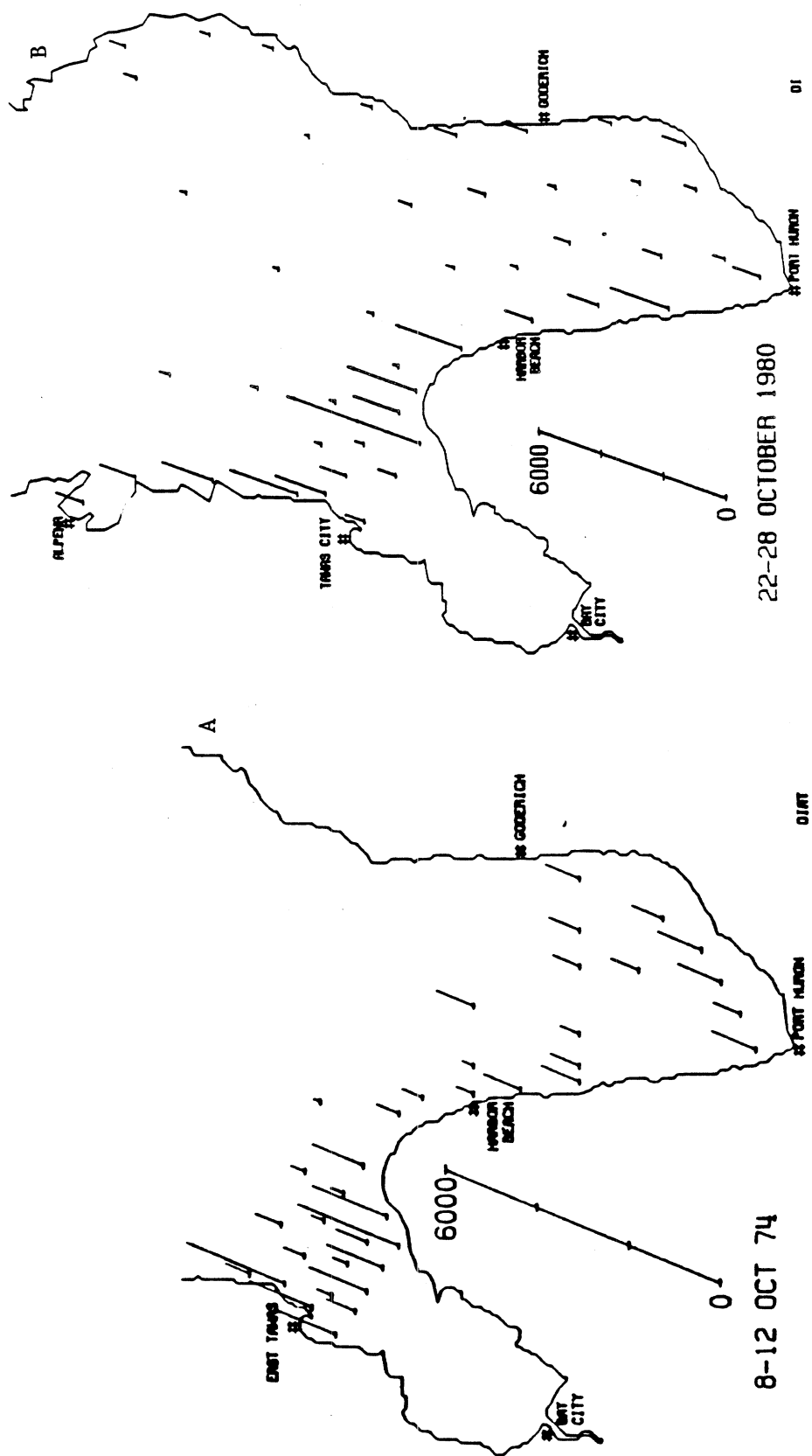


FIG. 76. Distribution and abundance (cells/mL) of diatoms, October 1974 (A) and 1980 (B).

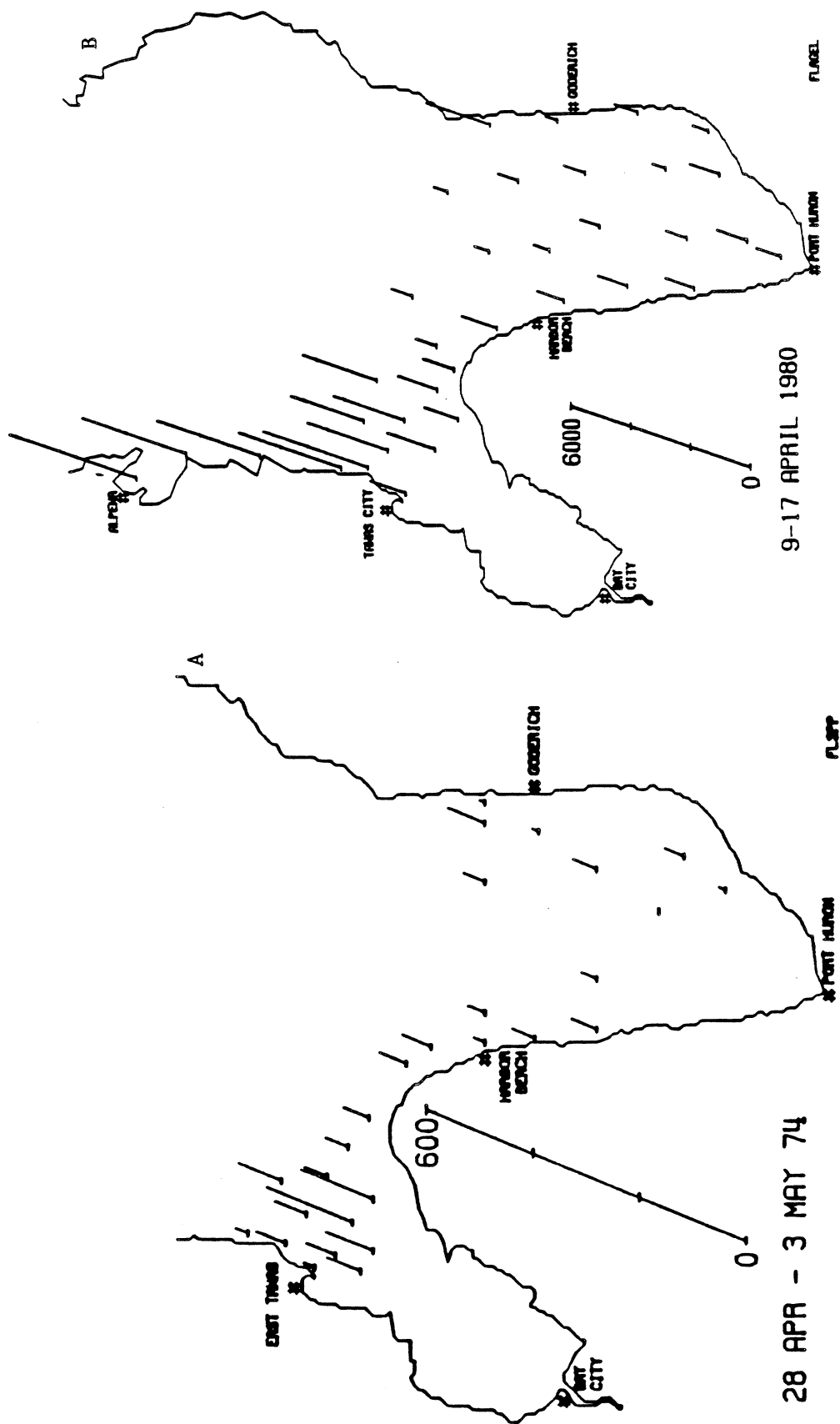


FIG. 77. Distribution and abundance (cells/mL) of phytoplankton, April 1974 (A) and 1980 (B).

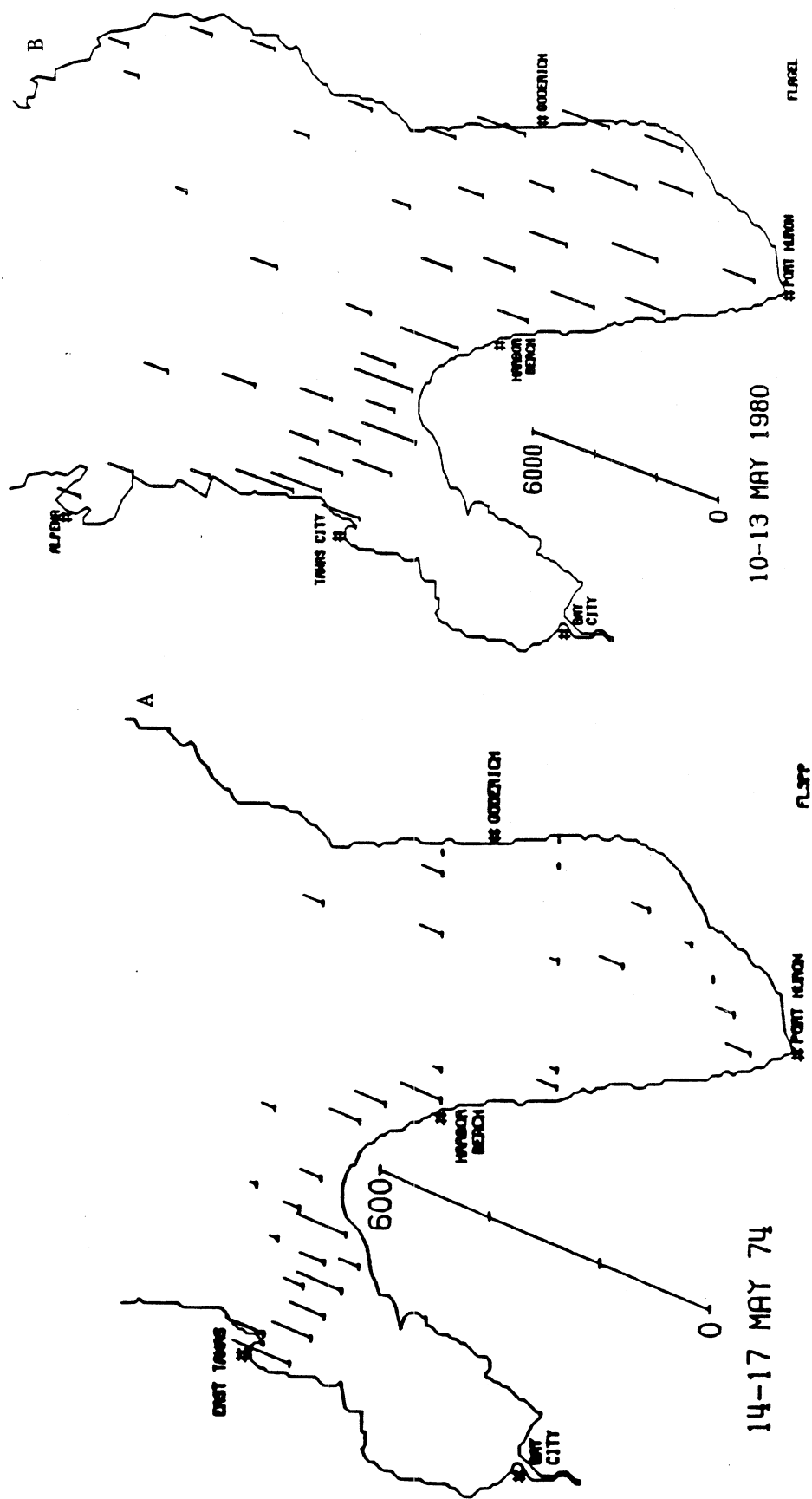


FIG. 78. Distribution and abundance (cells/mL) of phytoplankton, May 1974 (A) and 1980 (B).

again observed in outer Saginaw Bay during May 1980, but abundances were more uniform throughout the study area (Fig. 78B). In early June 1974, greatly elevated flagellate densities were observed in outer Saginaw Bay and adjacent waters compared to the offshore zone (Fig. 79A). Although flagellate standing crop in June 1980 was slightly higher in the Saginaw Bay interface zone compared to the remainder of the study area, densities were fairly uniform throughout (Fig. 79B). In July 1974 (Fig. 80A), flagellate abundance was highest in nearshore areas and Saginaw Bay. Conversely, flagellate standing crops were highest in offshore zones during July 1980 (Fig. 80B), compared to nearshore areas and outer Saginaw Bay. During October 1974 (Fig. 81A), highest abundances were again seen in Saginaw Bay and southward. During October 1980 (Fig. 81B), flagellate abundances were highest in outer Saginaw Bay and southward during both years but densities were fairly uniform throughout the survey area.

The seasonal patterns of chrysophytes were distinctly different between the two years, with highest abundances in the fall during 1974 and in the spring of 1980. Although densities were much higher in the spring of 1980 compared to 1974, abundances were similar for the fall months during both years. Chrysophytes are usually widely distributed in Lake Huron but several species typically show isolated peaks due to their colonial habit.

In April 1974, chrysophytes were represented throughout the study area with highest standing crops in the northeastern sector of Saginaw Bay (Fig. 82A). During April 1980, highest abundances were observed along the entire U.S. coastline (Fig. 82B). An isolated peak was also observed in the Canadian nearshore zone north of Goderich. During May of both years, highest densities were observed in outer Saginaw Bay and adjacent waters. In June

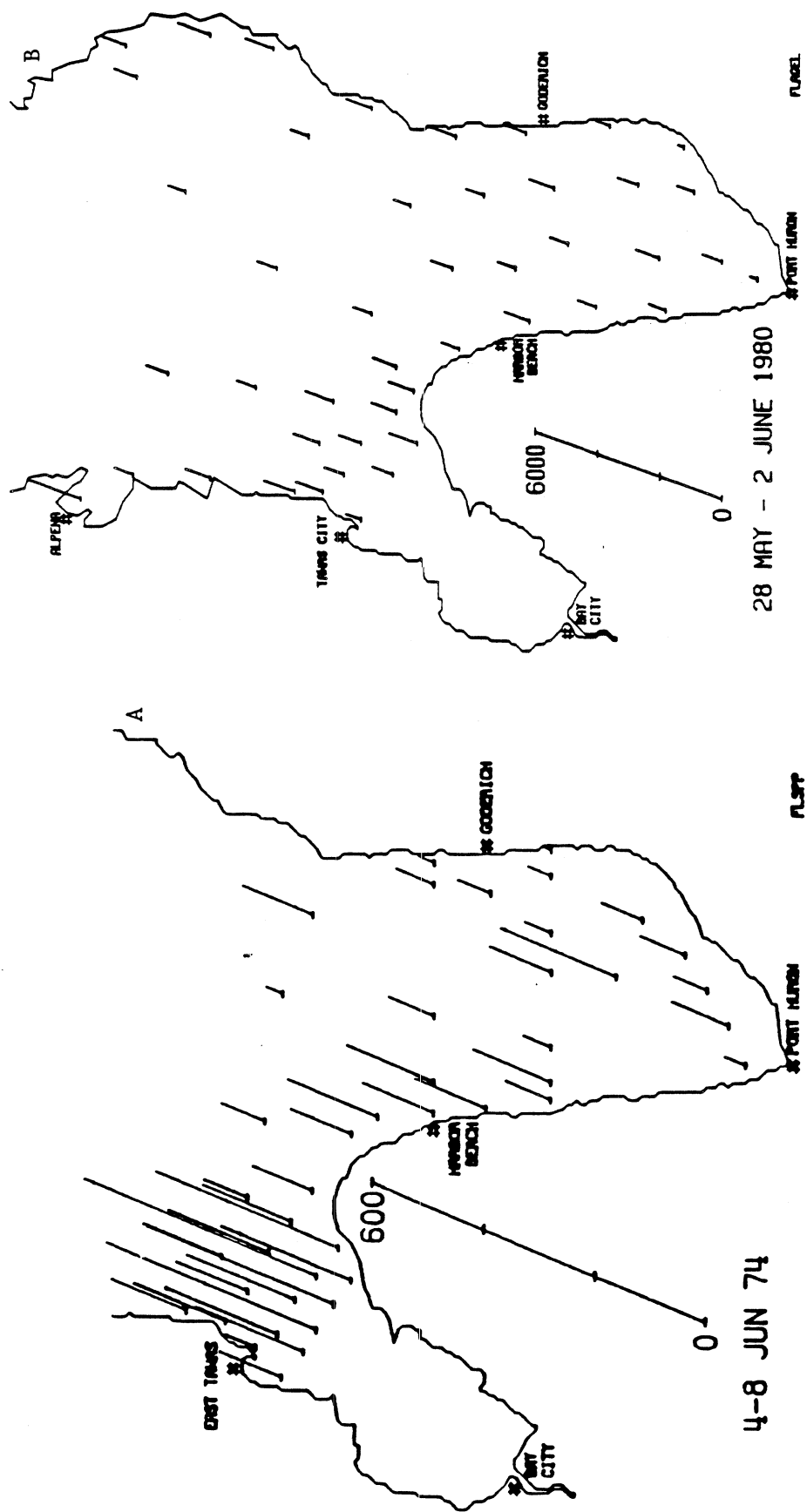


FIG. 79. Distribution and abundance (cells/mL) of phytoflagellates, June 1974 (A) and 1980 (B).

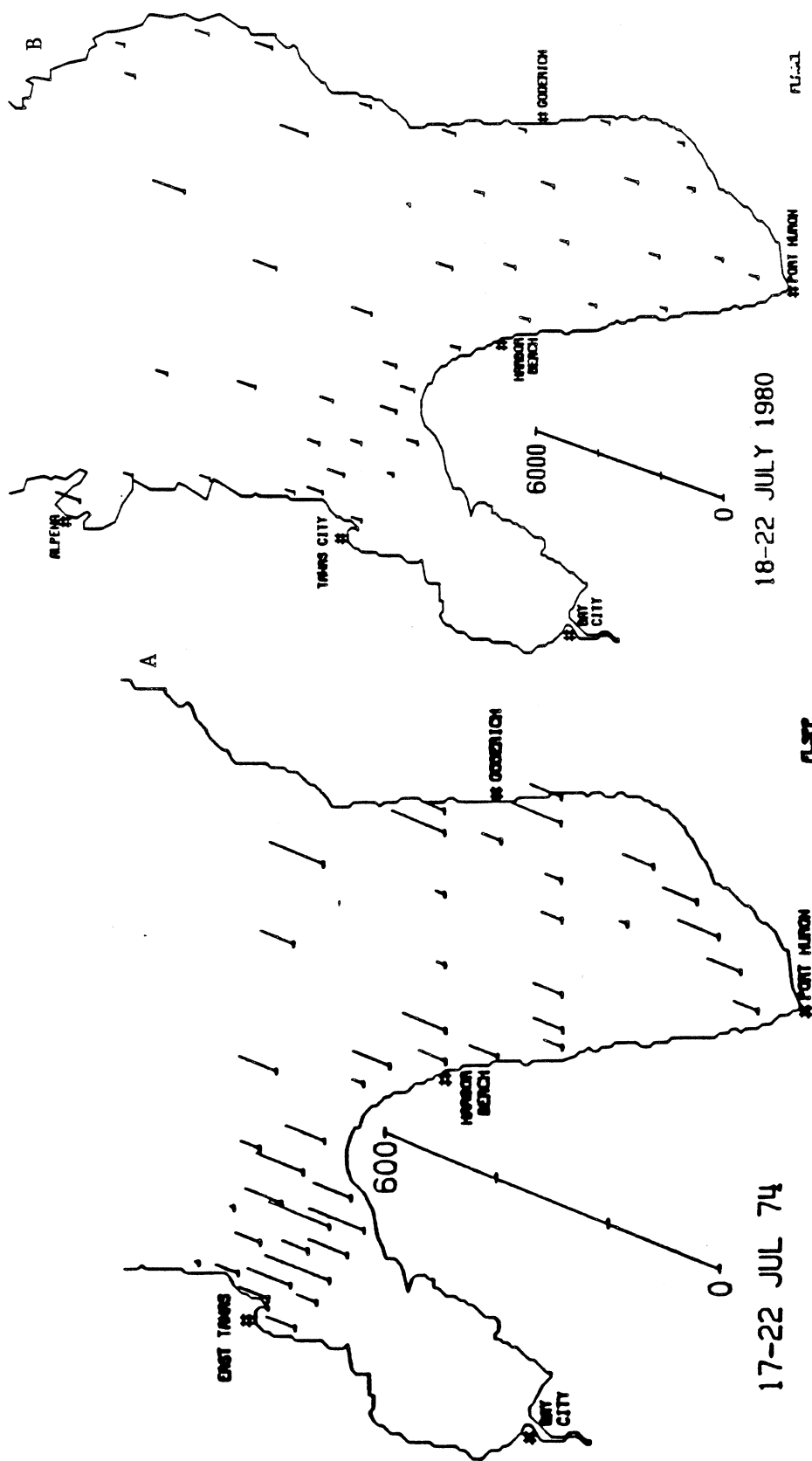


FIG. 80. Distribution and abundance (cells/mL) of phytoflagellates, July 1974 (A) and 1980 (B).

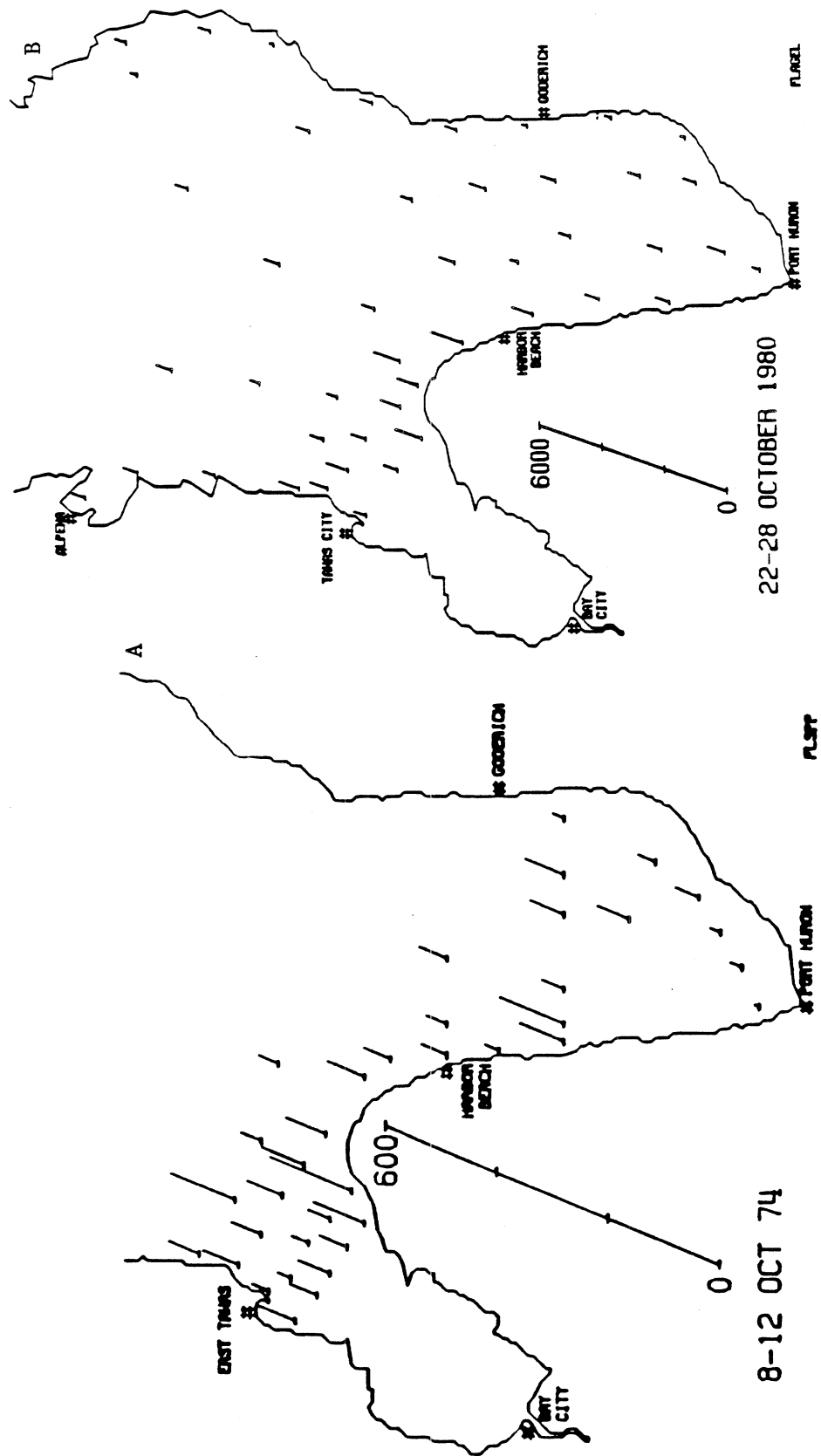


FIG. 81. Distribution and abundance (cells/mL) of phytoplankton, October, 1974 (A) and 1980 (B).

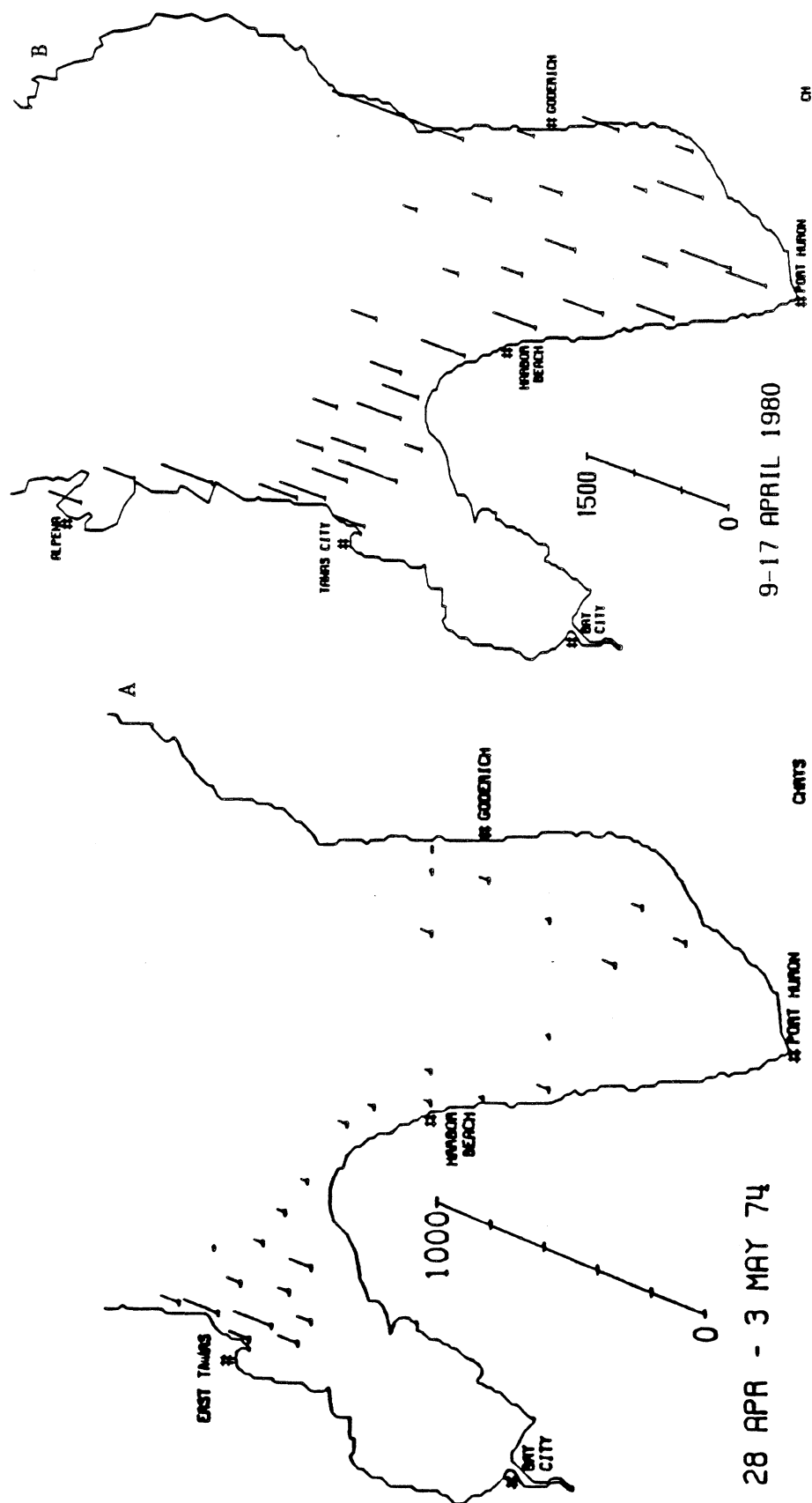


FIG. 82. Distribution and abundance (cells/mL) of chrysophytes, April 1974 (A) and 1980 (B).

1974, chrysophytes were again centered in outer Saginaw Bay and adjacent waters, extending southward into the mid-southern basin. Chrysophytes were widely distributed in uniform abundances throughout the study area in June 1980. Mean chrysophyte values were similar between the two years in July. In July 1974, largest numbers were centered in outer Saginaw Bay and the extreme lower end of the southern basin (Fig. 83A). During July 1980, high abundances were not observed in the lower southern basin (Fig. 83B). In October 1974, chrysophytes were in greatest abundance in outer Saginaw Bay and the northern interface zone (Fig. 84A). High cell densities were also observed on a north-south transect through the offshore waters of the southern basin. During October 1980, the southeastern sector of Saginaw Bay supported the highest densities, with lower abundances widely distributed over the remainder of the study area (Fig. 84B). Mean chrysophyte values were generally comparable during October of both years.

During both years, cryptomonads were widely distributed throughout Lake Huron. During April 1974, a large isolated peak was observed in Saginaw Bay and large abundances were also observed in the southern basin. In April 1980, cryptomonads were uniformly distributed over the study area. Cryptomonads were found in greatest abundance in outer Saginaw Bay in May 1974, with some elevated densities in the lower southern basin (Fig. 85A). In May 1980, high standing crops were generally observed in the offshore zone compared to Saginaw Bay and nearshore areas (Fig. 85B). In early and late June 1974, cryptomonads were centered in outer Saginaw Bay with some high abundances in the southern basin. In June 1980, densities were uniform throughout the study area. Cryptomonads were observed in greatest numbers in the offshore waters of the lower central basin and mid-southern basin during July 1974 (Fig. 86A).

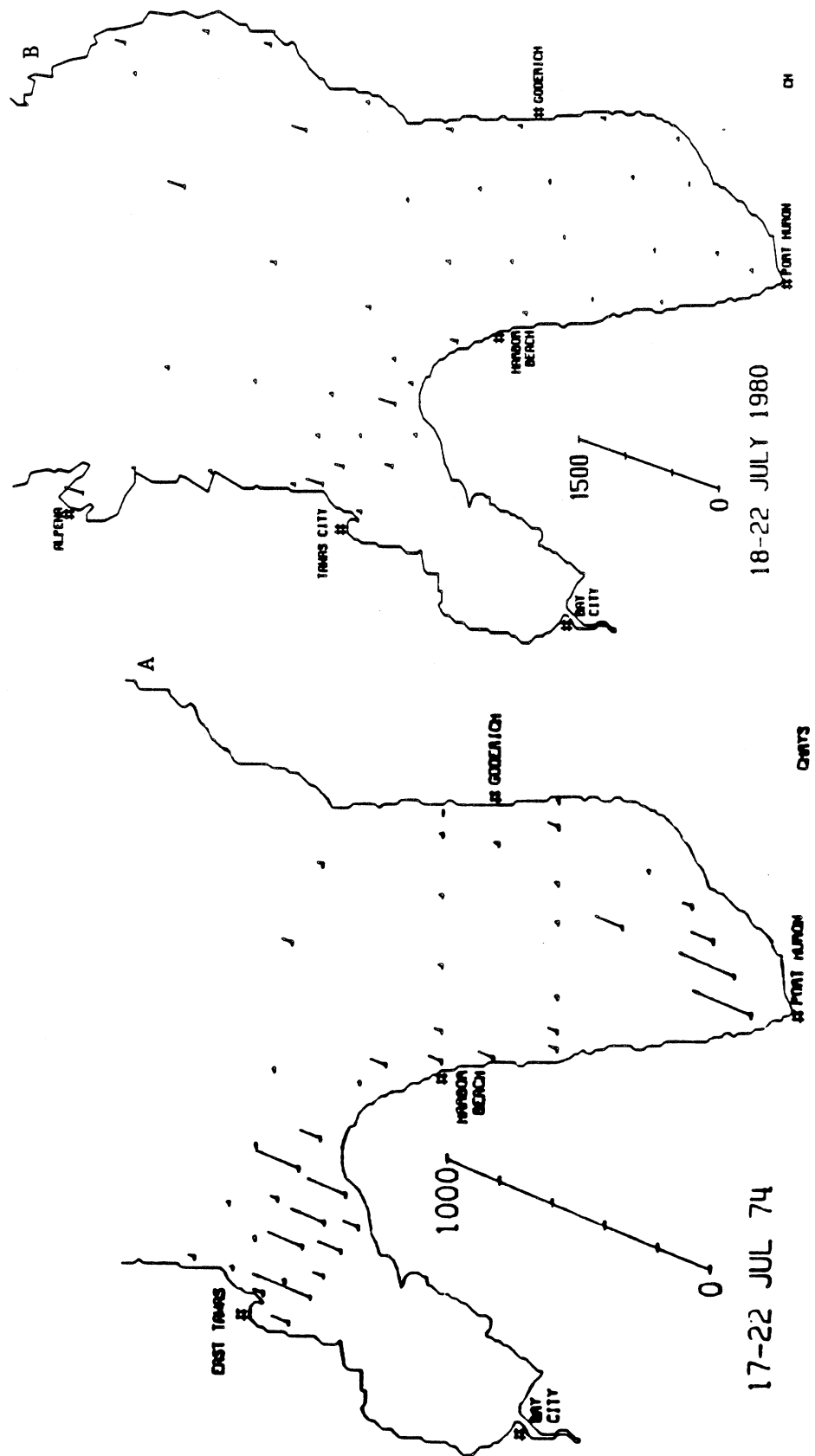


FIG. 83. Distribution and abundance (cells/mL) of chrysophytes, July 1974 (A) and 1980 (B).

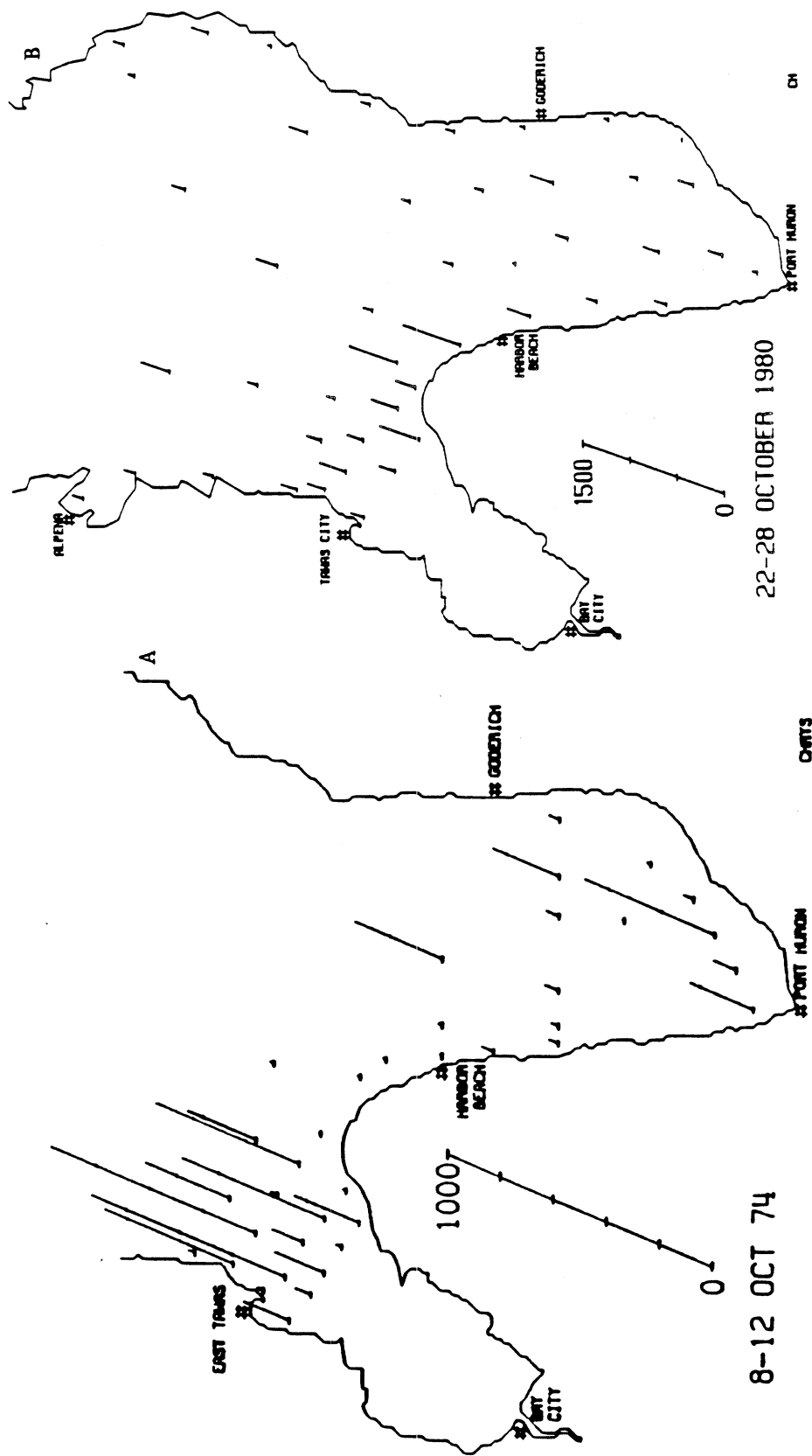


FIG. 84. Distribution and abundance (cells/mL) of chrysophytes, October 1974 (A) and 1980 (B).

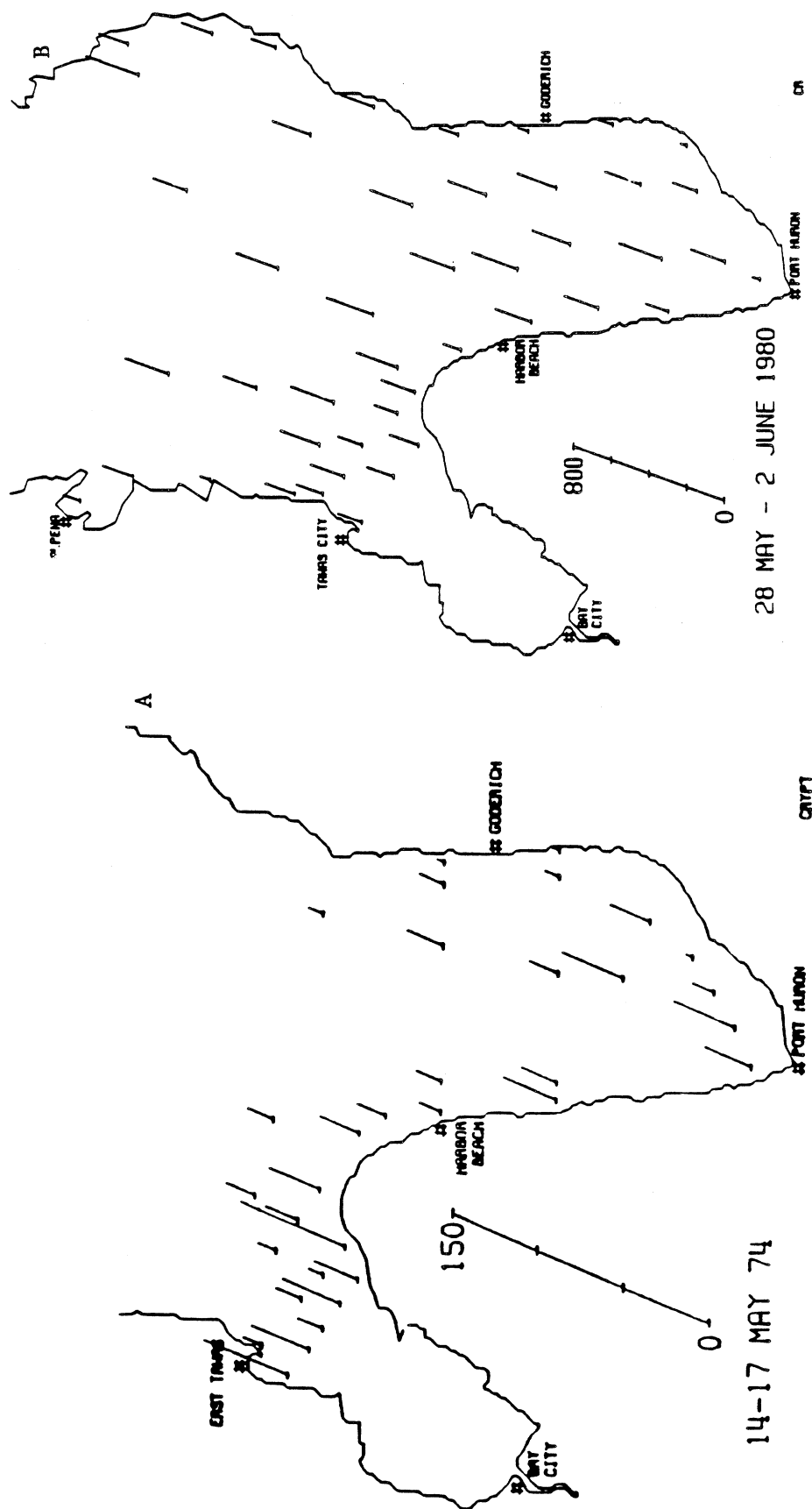


FIG. 85. Distribution and abundance (cells/mL) of cryptomonads, May 1974 (A) and 1980 (B).

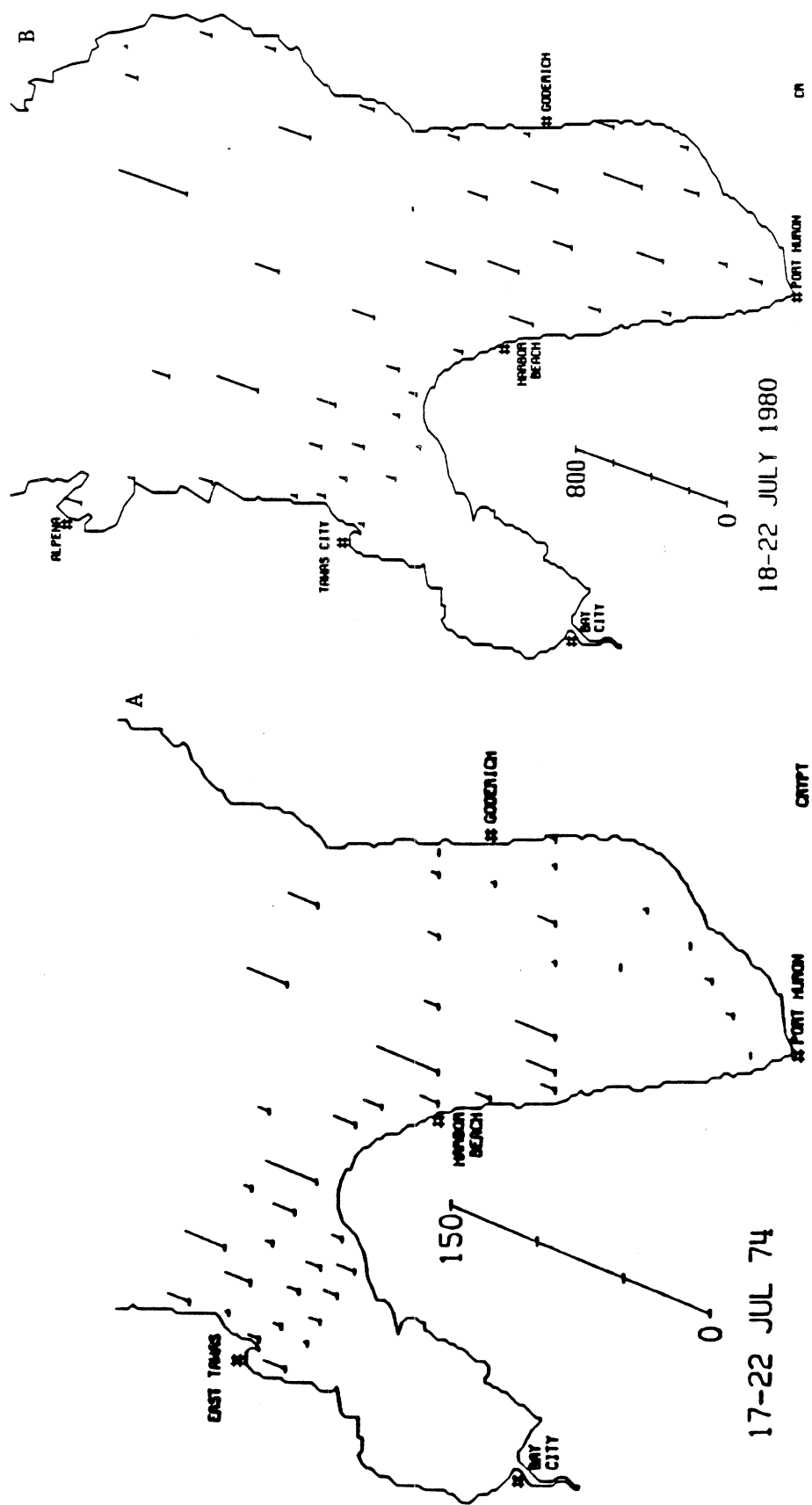


FIG. 86. Distribution and abundance (cells/mL) of cryptomonads, July 1974 (A) and 1980 (B).

During July 1980, cryptomonads were most abundant in the offshore zones of both basins, but were again distinctly lower in outer Saginaw Bay and nearshore areas (Fig. 86B). In October 1974, highest cryptomonad abundance was observed in the upper southern basin (Fig. 87A), whereas in October 1980, densities were uniformly distributed throughout the study area (Fig. 87B).

#### COMPARISON OF SEGMENT AVERAGES FOR MATCHED STATIONS, 1974 AND 1980

Since the sampling arrays in 1974 and 1980 differed, the use of matched or paired stations between years probably constitutes the most valid comparison. During 1974, segment 7a included stations farther into Saginaw Bay and showed seasonal patterns more closely aligned with the bay. During 1980, the central basin was sampled more extensively and affected the results for segment 6 and particularly for segment 7. The following comparisons use only the stations that were sampled during each year and present the most realistic picture of differences and similarities between years. Stations used in these analyses were two or less longitudinal and latitudinal degrees apart. Comparisons are made in regard to: (1) yearly abundances for all matched stations for each year within a segment, (2) yearly abundances for matched stations for each year between segments, and (3) monthly abundances between years within each segment.

Total phytoplankton abundance was typically greater and usually significantly higher ( $p < 0.05$ ) in segment 7a in 1974 and 1980 than for any other region in the study area (Fig. 88). This condition was also observed for all of the major physiological groups. Segment 7 also had significantly higher ( $p < 0.05$ ) algal standing crops than did segments 6 or 8 (Fig. 88). Therefore, the U.S. portion of southern Lake Huron generally supported higher

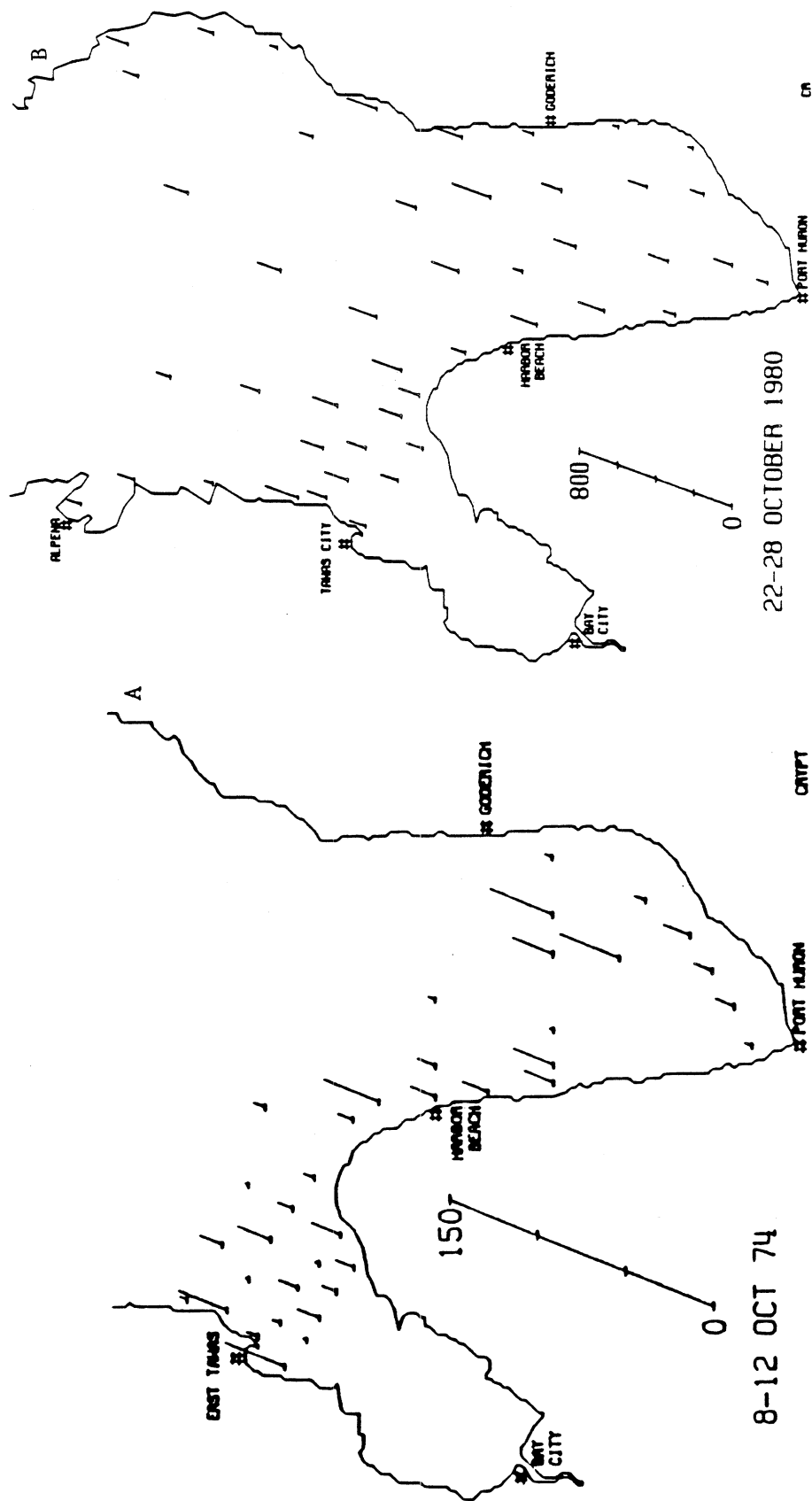


FIG. 87. Distribution and abundance (cells/mL) of cryptomonads, October 1974 (A) and 1980 (B).

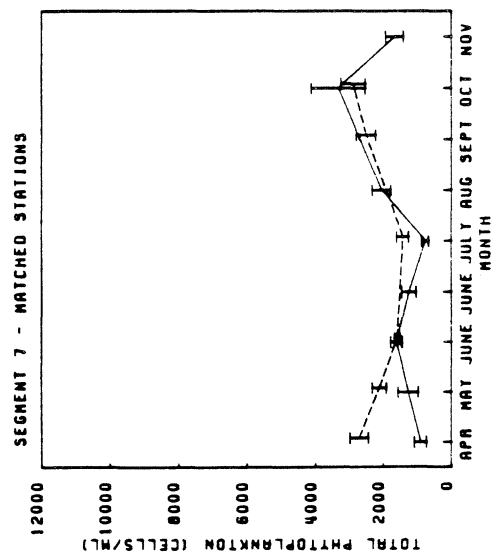
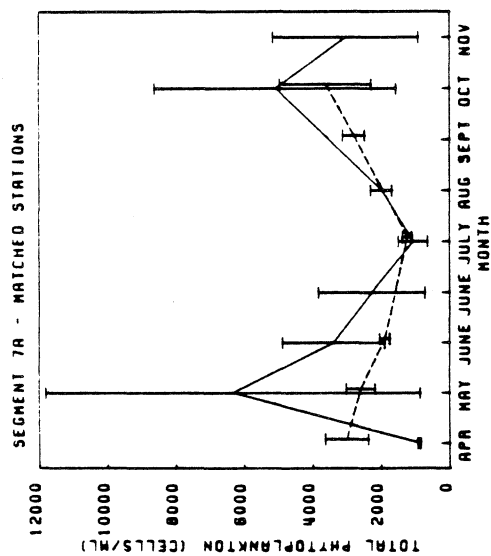
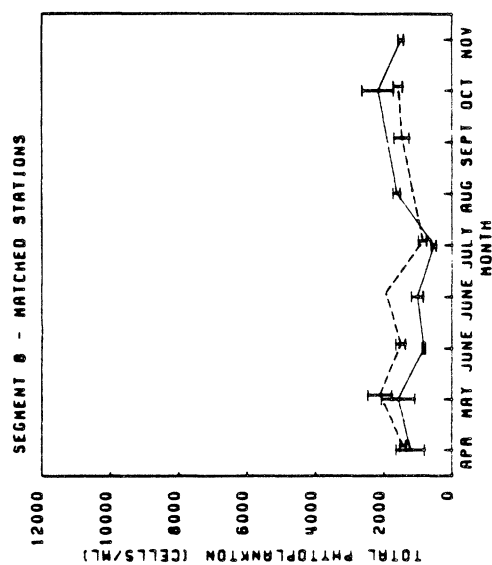
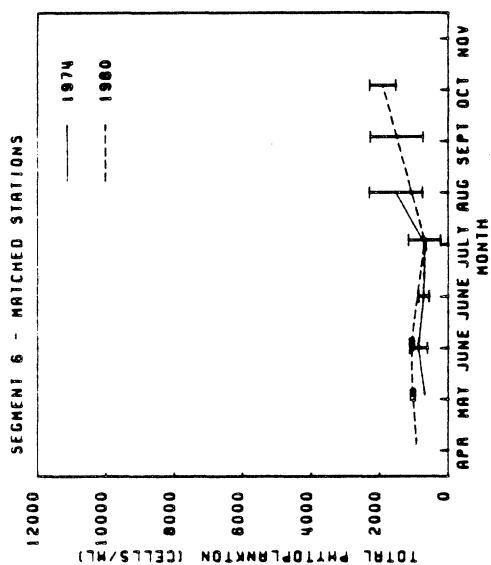


FIG. 88. Seasonal abundance of total phytoplankton for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

algal abundances than did the Canadian sector. Lowest algal standing crop was always recorded in the central basin (segment 6) followed by moderately higher abundances in segment 8. In all segments for both years, seasonal trends were bimodal patterns with peaks in the spring and fall and a summer minimum (Fig. 88).

In segment 7a, total phytoplankton densities were 14% lower in 1980 compared to 1974 (Fig. 88). The difference between years was not statistically significant ( $p < 0.05$ ), nor were significant differences ( $p < 0.05$ ) observed between monthly sampling periods. In segment 7, mean standing crop significantly increased ( $p < 0.05$ ) by 33% between years (Fig. 88). Significant increases ( $p < 0.05$ ) were observed during the spring and summer in April, May, and July between years. Mean algal standing crop was 32% greater in segment 6 during 1980 than in 1974 (Fig. 88), although the difference was not statistically significant ( $p < 0.05$ ). Significant differences ( $p < 0.05$ ) were not observed between monthly sampling periods. In segment 8, algal standing crop was 19% higher in 1980 than in 1974 (Fig. 88). The difference between years was not statistically significant ( $p < 0.05$ ). However, significant increases ( $p < 0.05$ ) were observed for June and July 1980 over the same months in 1974.

Blue-green algae in southern Lake Huron reached their highest abundance during the fall months and good agreement was observed in seasonal patterns in all segments between years (Fig. 89). However, higher blue-green standing crops were seen during the spring of 1980, compared to the spring of 1974 (Fig. 89), for most segments.

In segment 7a, blue-greens were 18% more abundant in 1980 than during 1974 but the differences in yearly abundance and for individual sampling periods were not statistically significant ( $p < 0.05$ ). Blue-green densities

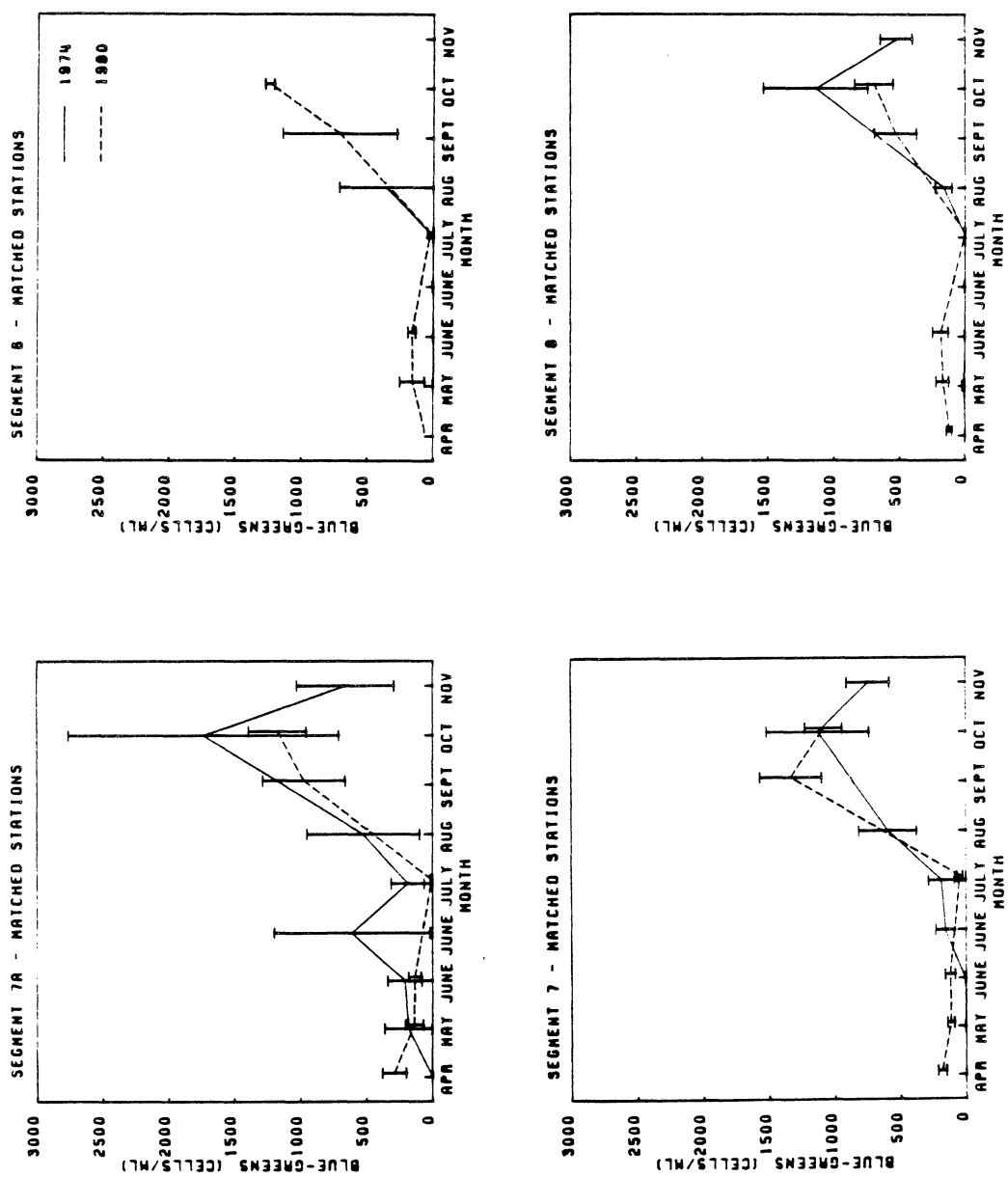


FIG. 89. Seasonal abundance of blue-green algae for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

were 25% greater in segment 7 during 1980 (Fig. 89), but the difference was not statistically significant ( $p < 0.05$ ). Significant increases ( $p < 0.05$ ) were observed for April, May, and June (Fig. 89) between years. On average, segment 6 showed a five-fold higher blue-green abundance in 1980 compared to 1974 (Fig. 89). This difference was not statistically significant ( $p < 0.05$ ), but a significant increase was observed in June 1980. Segment 8 also showed higher blue-green abundance in 1980 (Fig. 89) but the difference was not statistically significant ( $p < 0.05$ ). However, blue-greens were 43% more abundant in segment 8 during 1980 and significant increases ( $p < 0.05$ ) were obtained for April, May, and June 1980 between years (Fig. 89).

Green algae exhibited a bimodal seasonal pattern during 1974 in most segments, but this pattern was more strongly developed in segment 7a than in any other segment (Fig. 90). During 1980, uniform abundances were observed throughout the year in all segments. Green algal standing crop was significantly higher ( $p < 0.05$ ) in segment 7a during 1974 than in any other segment for either year (Fig. 90).

Largest absolute decreases of green algae between years were seen in segments 7a and 7 and significant yearly decreases ( $p < 0.05$ ) were observed in segments 7a, 7, and 8. Green algal abundance was 84% lower in segment 6 between years, but the difference was not statistically significant ( $p < 0.05$ ). No significant monthly differences ( $p < 0.05$ ) were observed in segment 6. Green algae decreased by 87% in segment 7a between years, but without significant decreases ( $p < 0.05$ ) between monthly periods (Fig. 90). A 73% reduction was recorded for segment 7 between years, and significant decreases ( $p < 0.05$ ) were observed for June and October between 1974 and 1980. Green algal standing

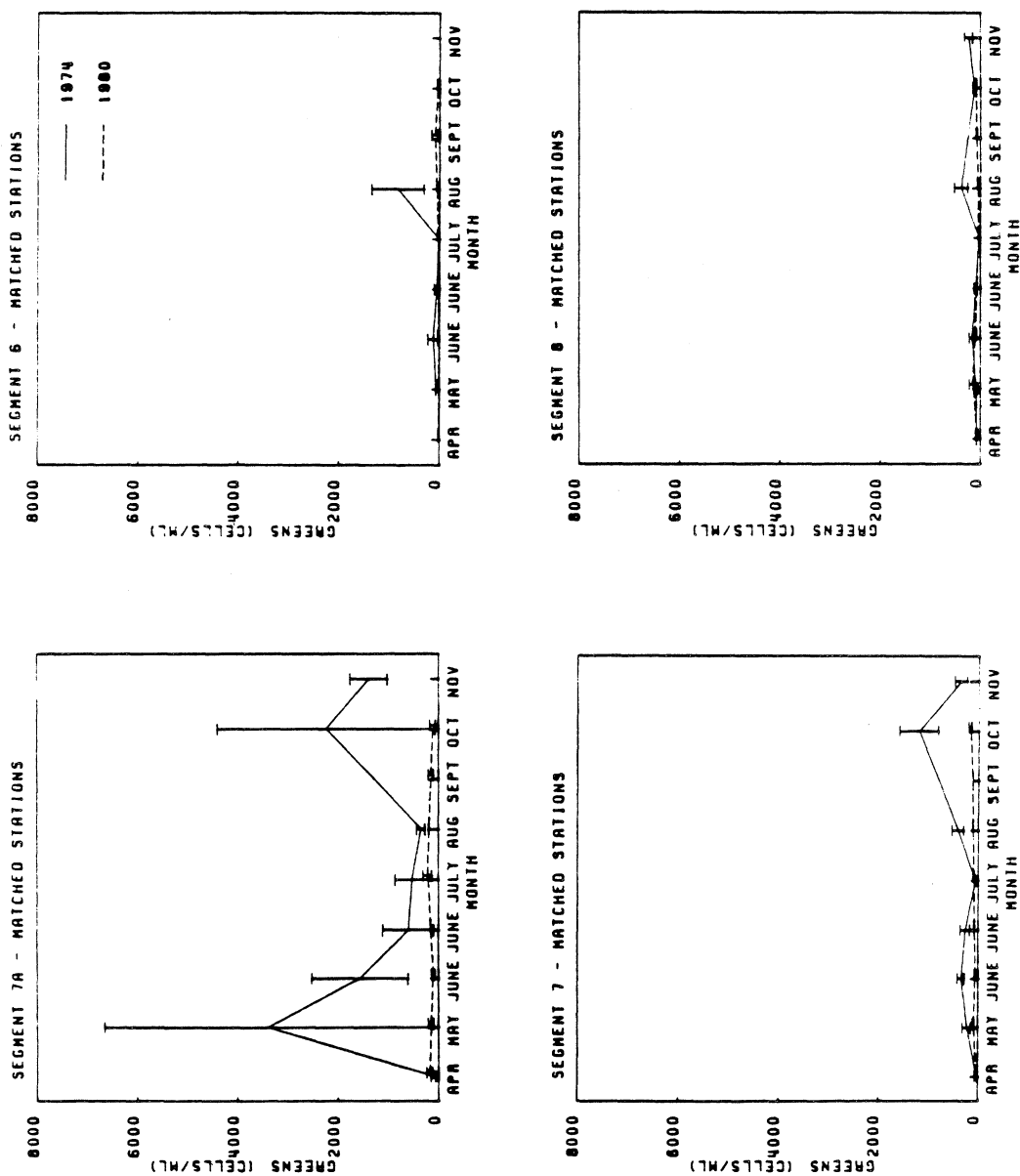


FIG. 90. Seasonal abundance of green algae for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

crop decreased by 41% in segment 8 between years, but no significant differences ( $p < 0.05$ ) were observed between monthly sampling periods (Fig. 90).

Seasonal trends of diatoms in southern Lake Huron differed substantially between years, particularly in the U.S. sector of the study area (Fig. 91). Segments 7a and 7 exhibited a bimodal diatom pattern during 1974, and typically, highest abundances were observed during the spring (Fig. 91). In segment 7a, and to a lesser extent in segment 7, diatom abundance in 1980 was greatest in the fall. In segment 7 during 1980, diatom standing crop was highest in the summer and fall (Fig. 91). Segment 8 exhibited an erratic seasonal pattern during 1974 with highest densities in the spring (Fig. 91). However, during 1980, abundances decreased throughout the season with a slight increase in October (Fig. 91). The seasonal pattern in segment 6 was weakly bimodal in 1980 (Fig. 91).

Diatom densities were highest in segment 7a, compared to the other segments during both years (Fig. 91). Diatom abundance in segment 7a was 24% greater in 1980 compared to 1974, but the difference was not statistically significant ( $p < 0.05$ ). Only one significant ( $p < 0.05$ ) monthly increase in July 1980 was observed between years. Diatoms were 5% greater in segment 7 during 1980, but were not significantly greater ( $p < 0.05$ ). In segment 7, a significant ( $p < 0.05$ ) monthly increase was observed in July and a significant decrease ( $p < 0.05$ ) was recorded for June between years.

Significant decreases ( $p < 0.05$ ) were observed in diatoms for segments 6 and 8. Segment 6 showed yearly diatom abundance decreasing by 44% between years with a significant decrease ( $p < 0.05$ ) recorded during July. Diatom standing crop decreased by 34% in segment 8 between years. However, no significant differences ( $p < 0.05$ ) were observed for monthly sampling periods.

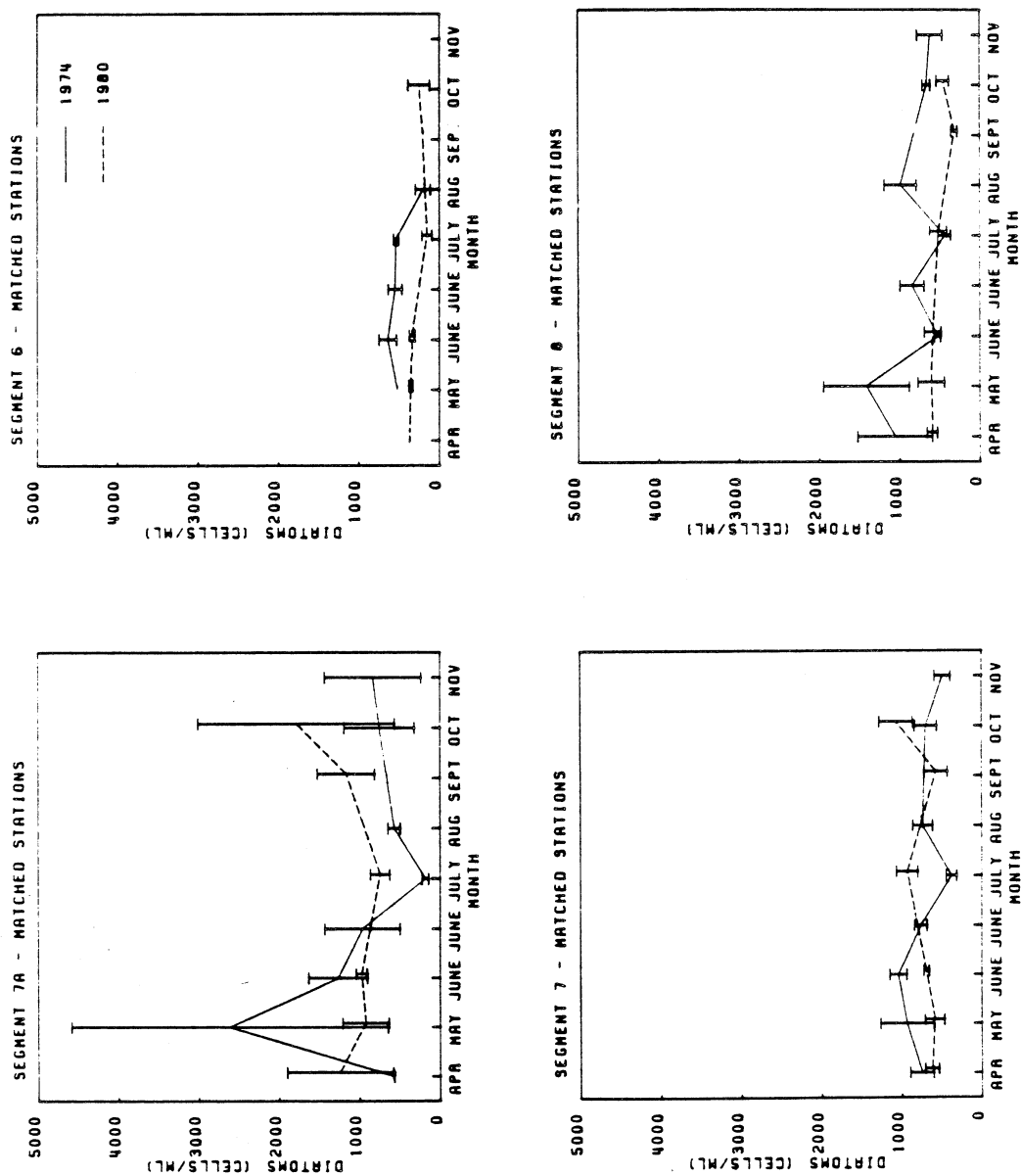


FIG. 91. Seasonal abundance of diatoms for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

Flagellates exhibited different seasonal patterns between years, with highest abundances in the fall of 1974, compared to highest densities during the spring of 1980 (Fig. 92). Yearly abundances of total phytoflagellates significantly increased ( $p < 0.05$ ) in all segments between 1974 and 1980 (Fig. 92). Microflagellates exhibited 3-, 5-, 6-, and 4-fold increases in segments 7a, 7, 8, and 6, respectively, between years. Typically, largest microflagellate standing crops were observed in segments 7 and 7a. Flagellates significantly increased ( $p < 0.05$ ) in segment 7a during April and May. However, microflagellates significantly increased ( $p < 0.05$ ) in segments 7 and 8 during all monthly sampling periods. Phytoflagellates significantly increased ( $p < 0.05$ ) during early June in segment 6 between years.

Cryptomonads exhibited similar seasonal patterns between years, generally reaching highest abundances during the spring months (Fig. 93). This pattern was more evident in 1980 than during 1974 (Fig. 93). However, significant increases ( $p < 0.05$ ) were recorded for all segments in 1980 with cryptomonads exhibiting 7-, 10-, 12-, and 5-fold increases in segments 7a, 7, 8, and 6, respectively, between years. Significant increases ( $p < 0.05$ ) were also observed in segments 7a, 7 and 8 for all monthly sampling periods. Segment 6 showed a significant increase ( $p < 0.05$ ) in cryptomonad abundance only during early June.

The seasonal pattern of chrysophytes differed sharply between 1974 and 1980 (Fig. 94). During 1974, highest chrysophyte abundance was observed during the fall, whereas during 1980, chrysophytes reached their highest standing crops in the spring (Fig. 94). Significant increases ( $p < 0.05$ ) were observed in chrysophyte abundance for segments 7, 8, and 6 between 1974 and 1980. Chrysophytes exhibited 2-, 2-, 4-, and 8-fold increases for segments

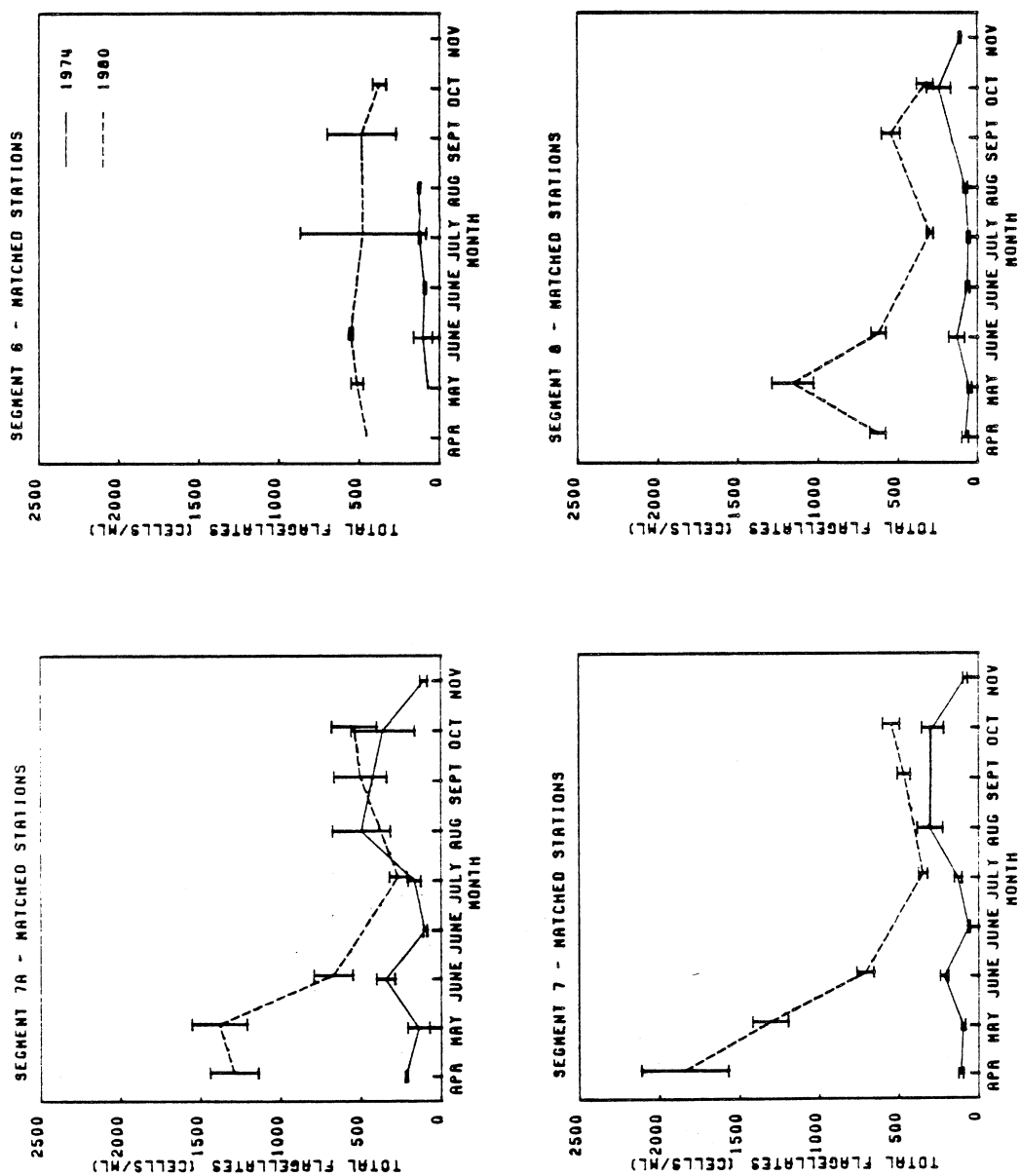


FIG. 92. Seasonal abundance of phytoflagellates for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

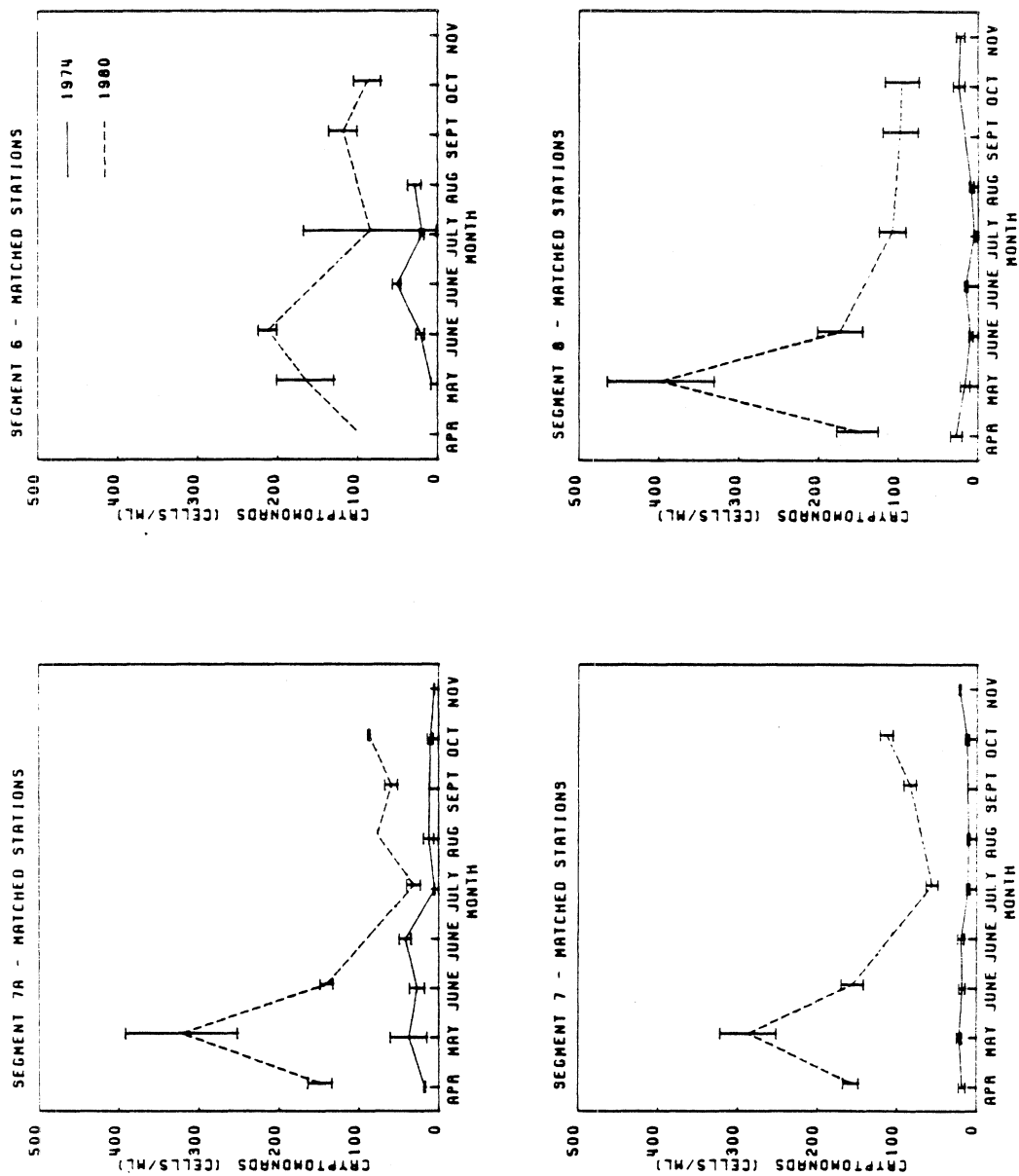


FIG. 93. Seasonal abundance of cryptomonads for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

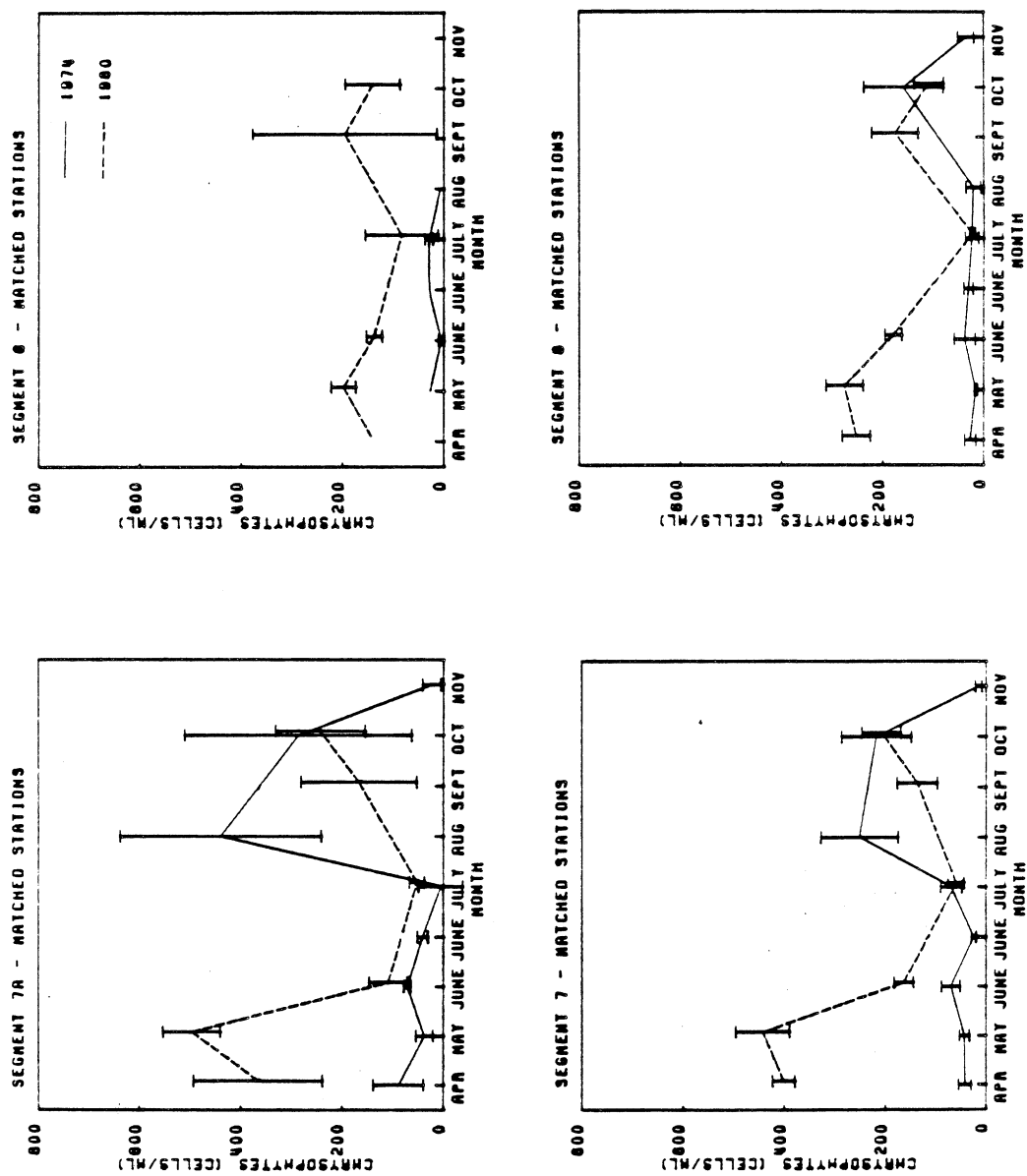


FIG. 94. Seasonal abundance of chrysophytes for matched stations by segment, 1974 and 1980. Error bars =  $\pm$  one standard error.

7a, 7, 8, and 6, respectively, between years. Although chrysophyte abundance was higher in the spring compared to the fall of 1980, monthly abundances between years during the fall months were similar. Significant increases ( $p < 0.05$ ) were observed in the spring months of April, May, and June in segments 7 and 8, May in segment 7a, and June in segment 6.

#### COMPARISON OF DISTRIBUTION AND ABUNDANCE TRENDS OF SELECTED SOUTHERN LAKE HURON ALGAL POPULATIONS, 1974 AND 1980

Several differences are apparent between the major algal divisions concerning their seasonal abundance and distribution patterns. However, numerous seasonal patterns exist for the array of species encountered in this study. Within an algal division, or for that matter within a single genus, contrasting distributional patterns are prevalent. Many of the differences are due to habitat preference or trophic association, controlled primarily by nutrient loading responses. In the following, the distributional patterns and abundances of species are compared for the same sampling period between years. The seasons compared are typically during peak abundance for the species and, in some cases, in regard to a specific lake region.

Generally, species which show substantial abundances and fairly well-known ecological preferences are discussed. There are many rare taxa and populations with poorly defined ecological preferences that were recorded during one year or another, and a few of these populations are also discussed. Also note that the abundance scales between years differ due to abundances encountered.

The differences in population abundance observed, when comparing 1974 to 1980, can be divided into six major categories: (1) eutrophic species observed during 1974 but absent in 1980, (2) eutrophic species with reduced abundances

in 1980, (3) offshore species with increased abundances in 1980, (4) offshore species with reduced abundances in 1980, (5) species with abundances remaining unchanged between years, and (6) species observed only during 1980. Species grouped in the first four categories are summarized in Table 28. The last two categories are discussed in the following text. A summary of mean species abundances for 1974 and 1980 is presented in Table 29.

Some species that were absent in 1980 did not show significant differences ( $p < 0.05$ ) between years. Similarly, some species that exhibited large absolute increases or decreases between 1974 and 1980 were not significantly different ( $p < 0.05$ ). In these cases, statistical differences were not obtained due to the large variances encountered.

The most striking feature when comparing blue-green species between years is the complete absence of some blue-green species from the flora of southern Lake Huron in 1980. Several of these species were prevalent or, in some cases, co-dominant in 1974. They are of particular interest since they were strongly associated with Saginaw Bay and are generally characteristic of eutrophic conditions.

Three blue-green species that were well-represented in 1974 were not detected during 1980. Aphanizomenon flos-aquae, Anabaena subcylindrica, and Oscillatoria retzii were present in 1974 but were not observed in the flora of southern Lake Huron during 1980. Aphanizomenon flos-aquae was abundant during the fall months of 1974, particularly during October, in outer Saginaw Bay and slightly southward along the U.S. coastal zone (Fig. 95). It was strongly associated with Saginaw Bay and is a well-known eutrophic blue-green alga. Aphanizomenon flos-aquae has been demonstrated to cause taste and odor problems in municipal water supplies and has been monitored in Saginaw Bay for

TABLE 28. Abundance differences in southern Lake Huron algal populations between 1974 and 1980.

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Eutrophic species eliminated from southern Lake Huron, 1980

<u>Anacystis dimidiata</u>	<u>Osillatoria retzii</u>
<u>Anabaena subcylindrica</u>	<u>Phacotus lenticularis</u>
<u>Aphanizomenon flos-aquae</u>	<u>Peridinium aciculiferum</u>

Eutrophic species with reduced abundances in southern Lake Huron, 1980

<u>Anabaena flos-aquae</u>	<u>Diatoma tenue</u> var. <u>elongatum</u>
<u>Anacystis cyanea</u>	<u>Fragilaria capucina</u>
<u>Gloeotila</u> sp.*	<u>Melosira granulata</u> *
<u>Mougeotia</u> sp. #1*	<u>Stephanodiscus binderanus</u>
<u>Actinocyclus normanni</u> fo. <u>subsalsa</u>	
<u>Cyclotella meneghiniana</u>	<u>Stephanodiscus tenuis</u>

Offshore species with increased abundances in southern Lake Huron, 1980

<u>Anacystis thermalis</u> *	<u>Cyclotella pseudostelligera</u> *
<u>Gomphosphaeria lacustris</u>	<u>Dinobryon divergens</u> *
<u>Oscillatoria bornetii</u> *	<u>Ochromonas</u> sp. #2*
<u>Schizothrix calcicola</u> *	<u>Rhodomonas minuta</u> *
<u>Ankistrodesmus</u> sp. #3*	<u>Rhodomonas minuta</u> var. <u>nannoplanctica</u> *
<u>Cyclotella comensis</u> *	<u>Flagellate</u> sp. #15*

Offshore species with reduced abundances in southern Lake Huron, 1980

<u>Gloeocystis planctonica</u> *	<u>Fragilaria crotonensis</u> *
<u>Asterionella formosa</u> *	<u>Fragilaria intermedia</u> var. <u>fallax</u>
<u>Cyclotella comta</u> *	<u>Rhizosolenia</u> spp.
<u>Cyclotella michiganiana</u> *	<u>Stephanodiscus transilvanicus</u>
<u>Cyclotella ocellata</u> *	<u>Synedra ostenfeldii</u>
<u>Cyclotella operculata</u> *	<u>Synedra ulna</u> var. <u>chaseana</u> *
<u>Cyclotella stelligera</u> *	<u>Tabellaria fenestrata</u> *
<u>Cyclotella</u> sp. #5*	<u>Cryptomonas ovata</u> *

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\*statistically significant ( $p < 0.05$ )

TABLE 29. Summary of mean abundances of southern Lake Huron algal species for all cruises and matched stations, 1974 and 1980.

<u>TAXON</u>	<u>1974</u>	<u>1980</u>
	<u><math>\bar{x}</math></u>	<u><math>\bar{x}</math></u>
<u>Anabaena flos-aquae</u>	16.8	1.0
<u>Ankistrodesmus</u> sp.#3 *+	3.5	6.2
<u>Asterionella formosa</u> *-	36.6	28.3
<u>Anacystis incerta</u>	124.0	172.0
<u>Anacystis thermalis</u> *+	11.9	28.7
<u>Aphanizomenon flos-aquae</u>	39.6	0
<u>Cryptomonas ovata</u> *-	6.0	4.0
<u>Chrysococcus dokidophorus</u>	3.9	3.4
<u>Cyclotella comensis</u> *+	148.5	321.3
<u>Cyclotella comta</u> *-	4.9	2.2
<u>Cyclotella michiganiana</u> *-	14.4	2.6
<u>Cyclotella ocellata</u> *-	24.3	14.0
<u>Cyclotella operculata</u> *-	2.4	0.7
<u>Cyclotella pseudostelligera</u> *+	0.2	2.4
<u>Diatoma tenue</u> var. <u>elongatum</u>	9.5	5.6
<u>Dinobryon divergens</u> *+	13.3	27.6
Flagellate sp.#15 *+	0	72.5
<u>Fragilaria capucina</u>	72.4	72.6
<u>Fragilaria crotonensis</u> *-	95.1	54.2
<u>Fragilaria pinnata</u> *+	3.4	10.1
<u>Gloeocystis planctonica</u> *-	53.4	17.5
<u>Gomphosphaeria lacustris</u>	100.9	132.1
<u>Gloeotila</u> sp. *-	315.5	16.6
<u>Melosira granulata</u> *-	3.8	0.3
<u>Monochrysis aphanaster</u> *+	0	3.8
<u>Mougeotia</u> sp.#1 *-	7.9	0.4

\*statistically significant ( $p < 0.05$ )  
+ or - trend indication

(continued)

TABLE 29. (continued).

<u>TAXON</u>	<u>1974</u>	<u>1980</u>
	<u><math>\bar{x}</math></u>	<u><math>\bar{x}</math></u>
<u>Nitzschia acicularis</u> *-	5.4	3.6
<u>Nitzschia dissipata</u> *-	2.5	0.7
<u>Ochromonas</u> sp.#2 *+	3.7	124.7
<u>Oscillatoria bornetii</u> *+	1.9	47.5
<u>Rhodomonas minuta</u> *+	0.5	28.7
<u>Rhodomonas minuta</u> var. <u>nannoplanctica</u> *+	9.1	76.4
<u>Rhizosolenia eriensis</u> *-	48.0	28.0
<u>Scenedesmus quadricauda</u>	1.6	2.2
<u>Stephanodiscus alpinus</u>	3.8	0.6
<u>Stephanodiscus binderanus</u>	4.3	1.7
<u>Stephanodiscus hantzschii</u>	10.7	1.8
<u>Stephanodiscus minutus</u>	10.2	10.0
<u>Synedra filiformis</u> *-	46.3	20.3
<u>Synedra ostenfeldii</u> *-	7.3	2.9
<u>Synedra ulna</u> var. <u>chaseana</u> *-	1.9	0.8
<u>Schizothrix calcicola</u> *+	0.3	13.0
<u>Tabellaria fenestrata</u> *-	53.4	31.2
<u>Tabellaria flocculosa</u> var. <u>linearis</u> *-	25.6	13.1

\*statistically significant ( $p < 0.05$ )

+ or - trend indication

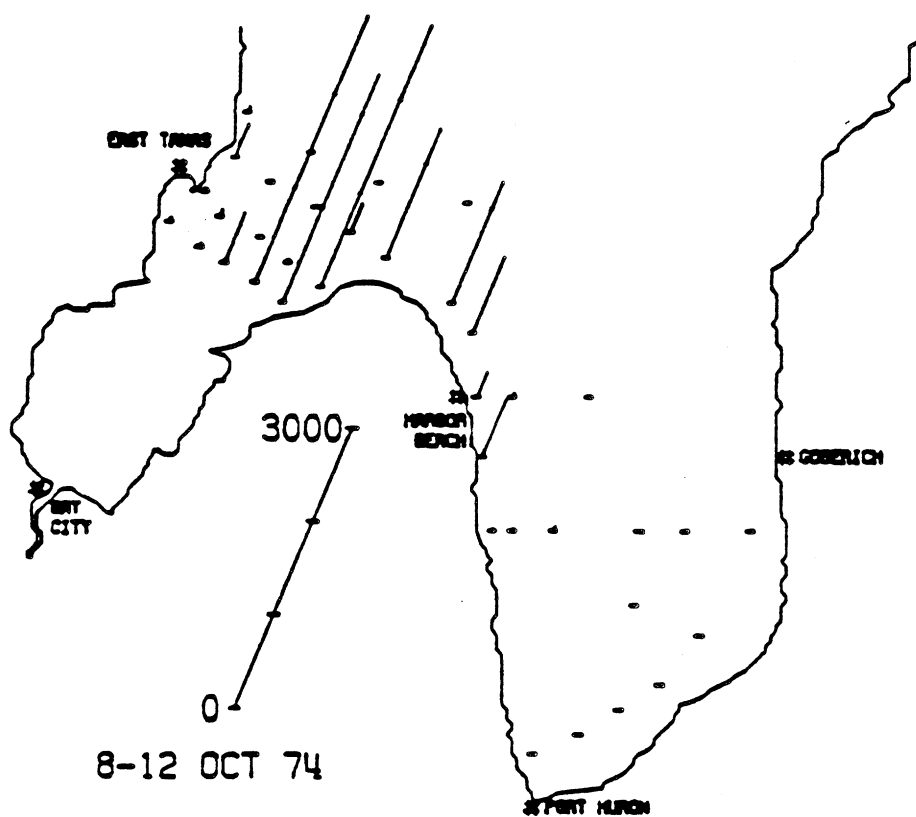


FIG. 95. Distribution and abundance (cells/mL) of Aphanizomenon flos-aquae, October 1974.

such nuisances (Bierman et al. 1984). The other taxa, Anabaena subcylindrica and Oscillatoria retzii (Fig. 96), have poorly-known trophic preferences in the Great Lakes, but were representative of the Saginaw Bay flora in 1974. Schelske et al. (1974a) noted that largest densities of Anabaena subcylindrica were found in Saginaw Bay during 1972 but appeared to be transported to the open lake. Anacystis dimidiata, although not found in high abundances in 1974, was another species highly associated with Saginaw Bay and was not detected in 1980.

Another blue-green alga which occurs in eutrophic habitats and was associated with Saginaw Bay in 1974 was Anabaena flos-aquae (Fig. 97A). This species was significantly reduced ( $p < 0.05$ ) in 1980 and was the only heterocystous blue-green observed. In October of 1980, Anabaena flos-aquae was recorded in its highest density at an isolated station in Saginaw Bay, with a lower abundance observed in the northern Canadian nearshore zone (Fig. 97B). The comparison, in this case, is not between months, but Anabaena flos-aquae was observed in very low numbers in June 1980. These figures demonstrate a seasonal shift in peak abundance between years.

Anacystis cyanea is a well-known nuisance species which was well represented in outer Saginaw Bay during 1974. It typically blooms in small eutrophic lakes during the summer and fall with Aphanizomenon flos-aquae and Anabaena flos-aquae. Anacystis cyanea was substantially reduced in abundance and occurrence in 1980.

Anacystis incerta is commonly observed in the offshore waters of the Great Lakes during the late summer and fall. Between October 1974 (Fig. 98A) and October 1980 (Fig. 98B), it showed a slight decrease in abundance, particularly in the southern basin. However, considering all sampling periods

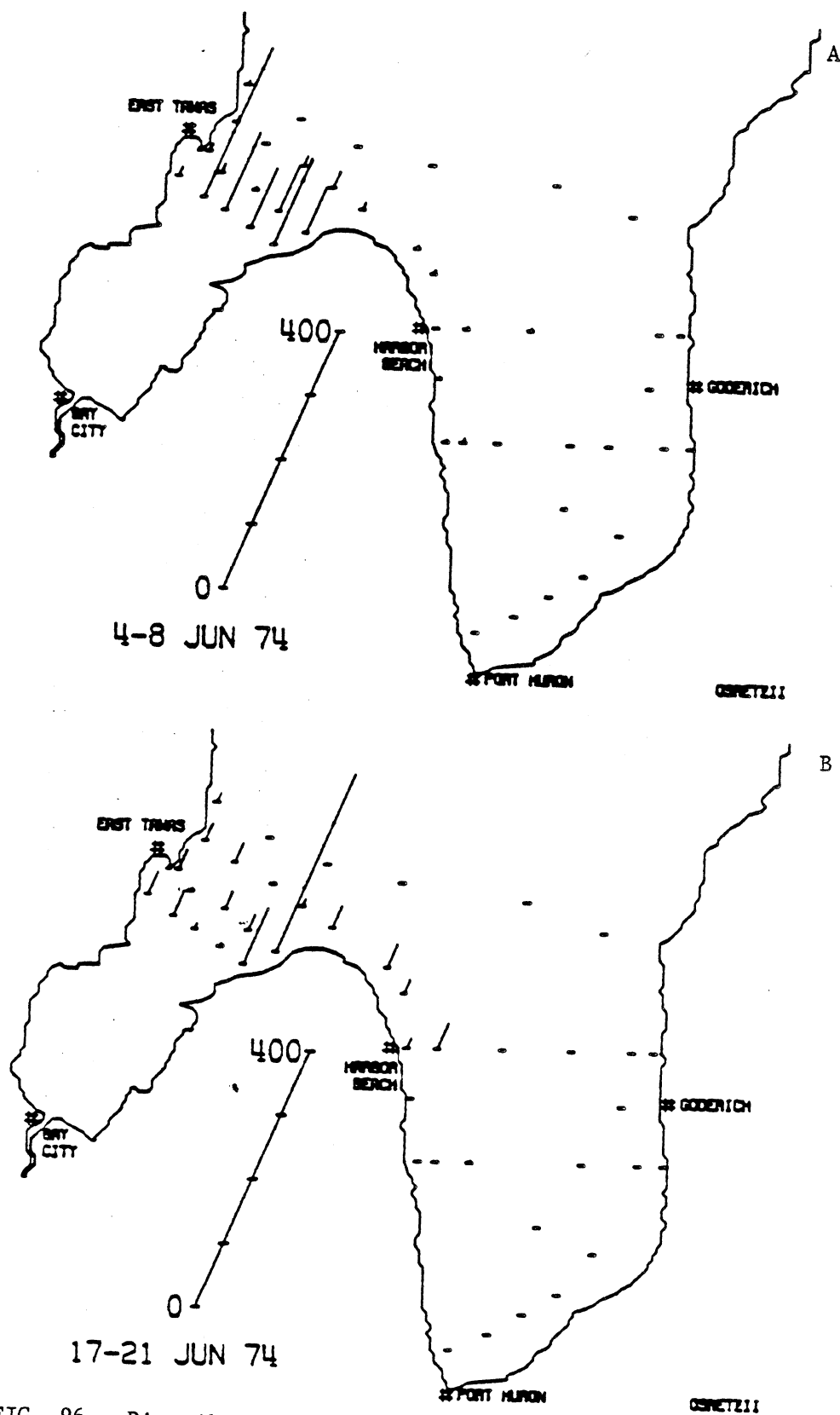


FIG. 96. Distribution and abundance (cells/mL) of *Oscillatoria retzii*, June 1974.

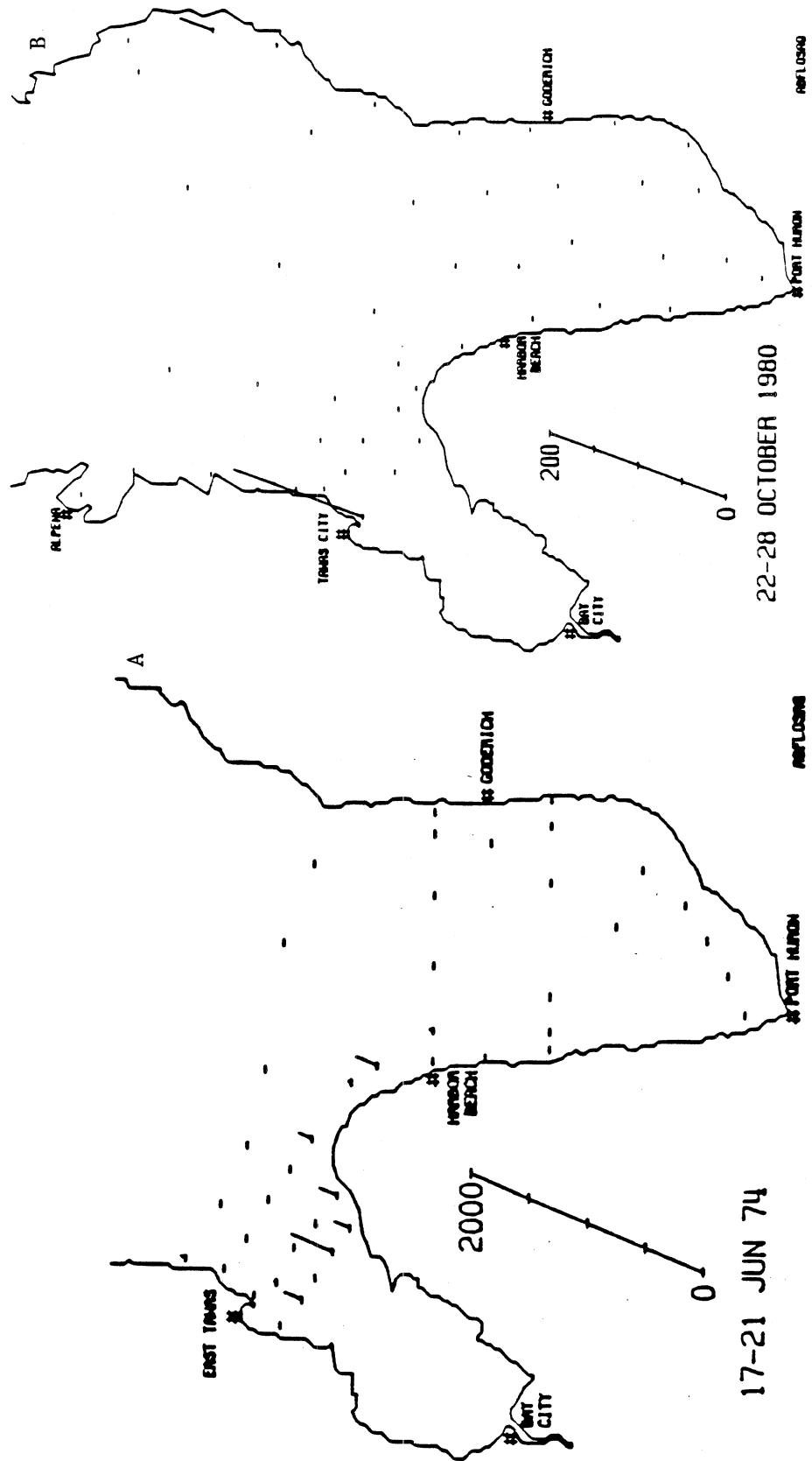


FIG. 97. Distribution and abundance (cells/mL) of *Anabaena flos-aquae*, June 1974 (A) and October 1980 (B).

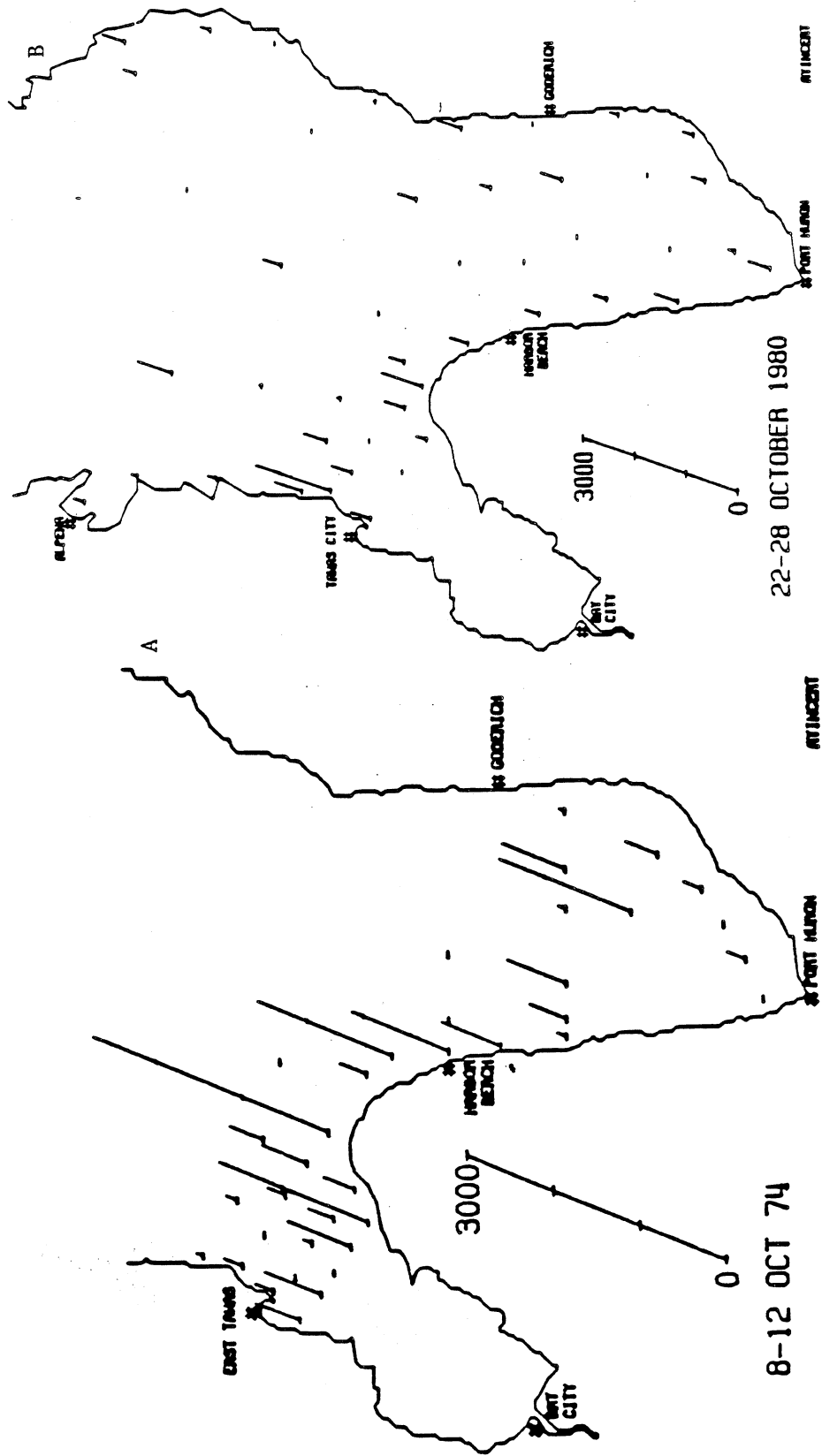


FIG. 98. Distribution and abundance (cells/mL) of Anacystis incerta, October 1974 (A) and 1980 (B).

for each year, this taxon showed little change in occurrence or mean abundance.

Three blue-greens that are commonly observed in offshore waters increased between 1974 and 1980. Oscillatoria bornetii showed a significant increase ( $p < 0.05$ ) between years (Figs. 99A and B). Oscillatoria bornetii and Schizothrix calcicola, which was also significantly higher ( $p < 0.05$ ), were the species primarily responsible for the spring increases in most regions of the lake during 1980. Their autecologies are not well-known. However, they are typically observed throughout most seasons in low abundances in the Great Lakes. Gomphosphaeria lacustris also substantially increased in 1980 but was predominantly a fall species.

Green algae markedly declined in all regions of the study area between 1974 and 1980. Those showing the greatest reductions were usually associated with Saginaw Bay. One species that was confined to outer Saginaw Bay in 1974, Phacotus lenticularis, was not observed in 1980. Although its abundance was low in 1974, it was a eutrophic species absent from southern Lake Huron during 1980. Two green algae that showed drastic decreases in outer Saginaw Bay were Gloeotila sp. and Mougeotia sp. #1. Both are filamentous greens which could not be confidently assigned at the species level. In 1974, Gloeotila sp. was dominant at numerous stations in outer Saginaw Bay and in waters south of the bay (Fig. 100A). It was prevalent during the mid-spring and sustained large abundances throughout the fall months. During 1980, it was significantly reduced ( $p < 0.05$ ) and showed a sporadic distribution (Fig. 100B). Mougeotia sp. #1 was abundant during the fall months in 1974 (Figs. 101A and B), but declined significantly ( $p < 0.05$ ) in 1980, showing mean abundances and occurrences 7-fold less than in 1974. Other green algae that showed

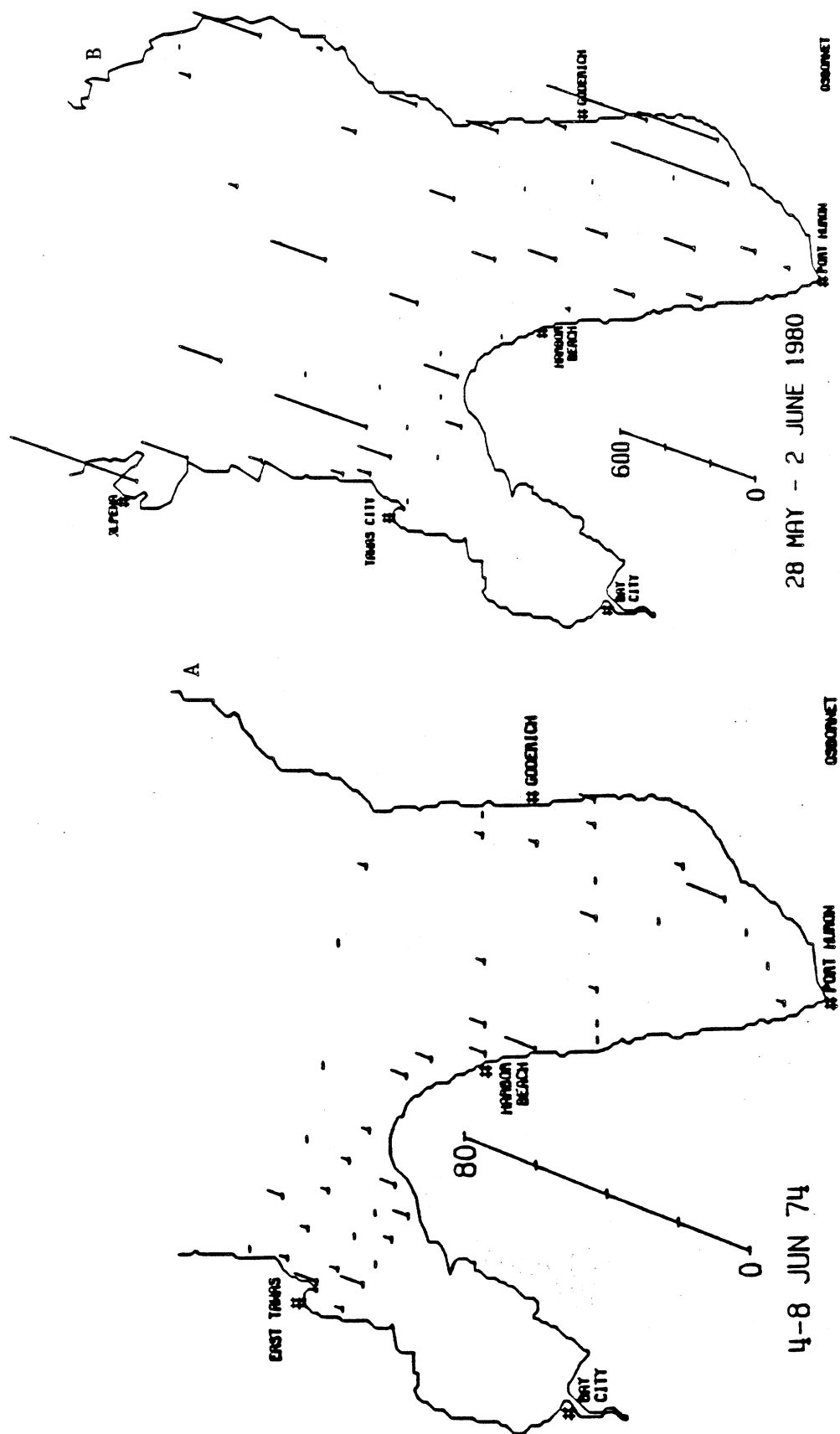


FIG. 99. Distribution and abundance (cells/mL) of *Oscillatoria bornetii*, June 1974 (A) and 1980 (B).

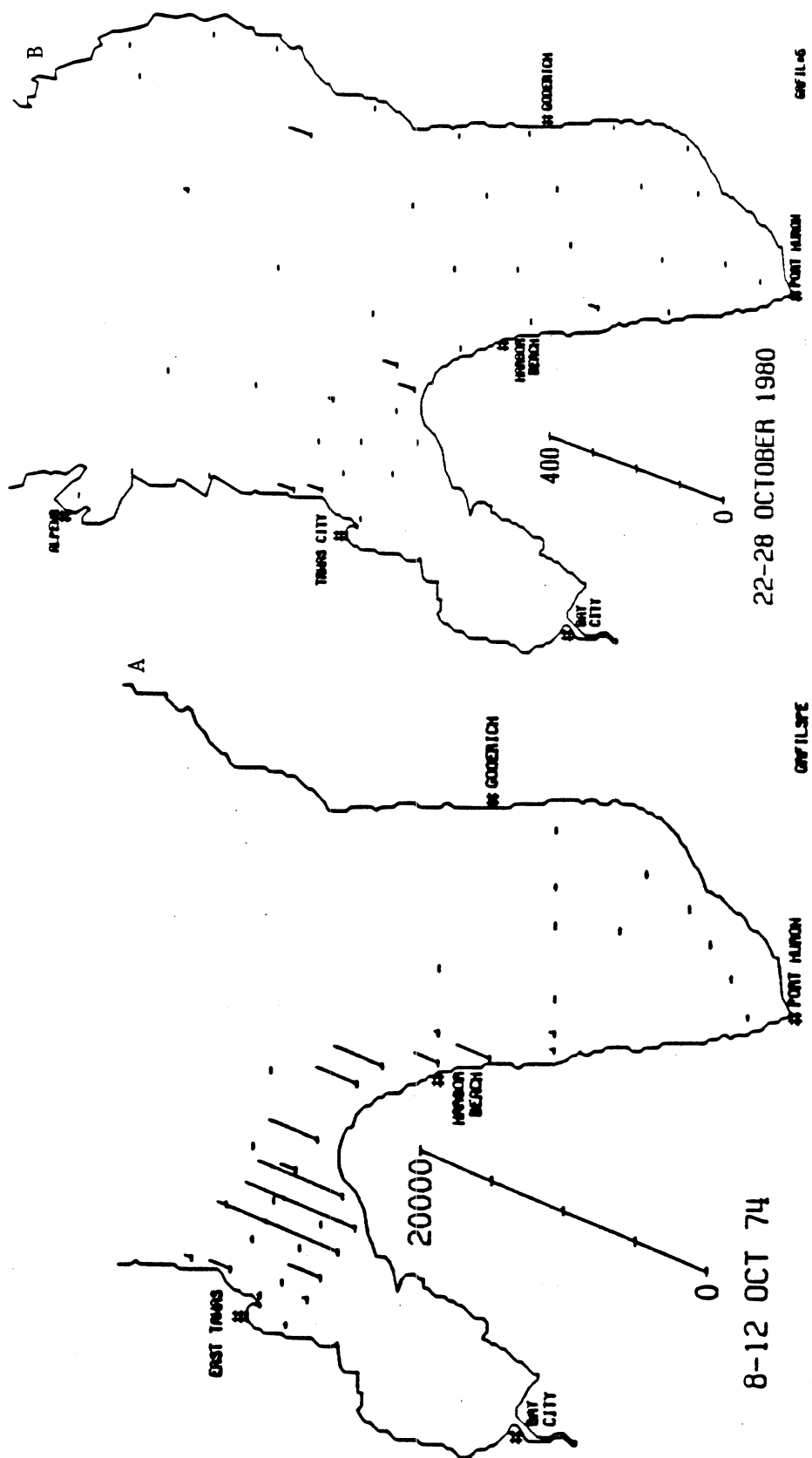


FIG. 100. Distribution and abundance (cells/mL) of *Gloeotila* sp., October 1974 (A) and 1980 (B).

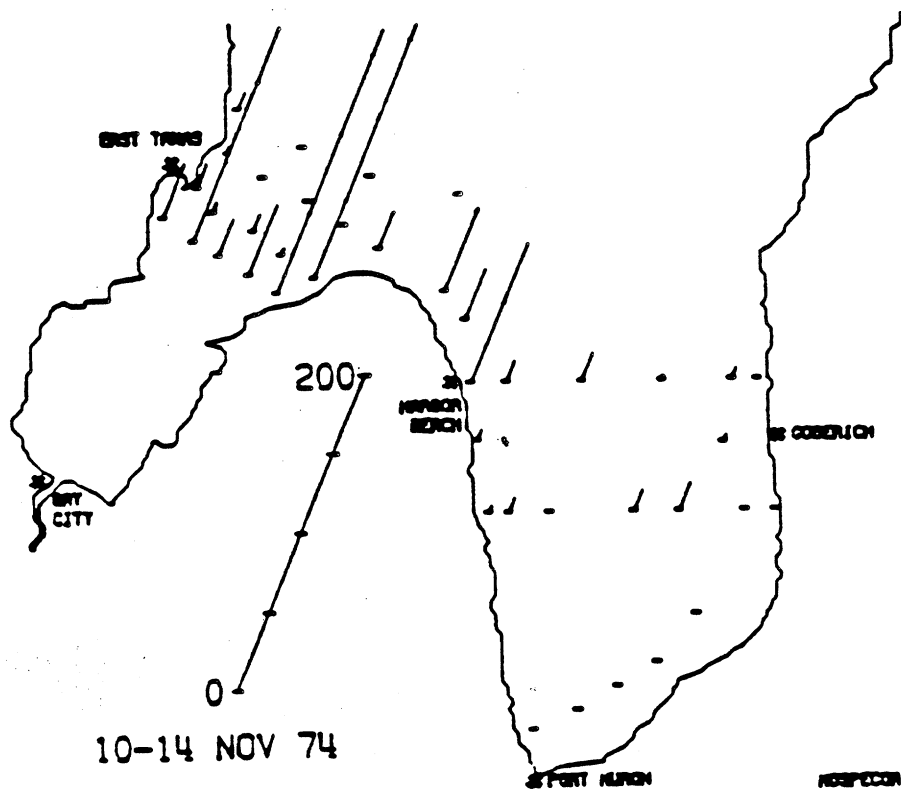
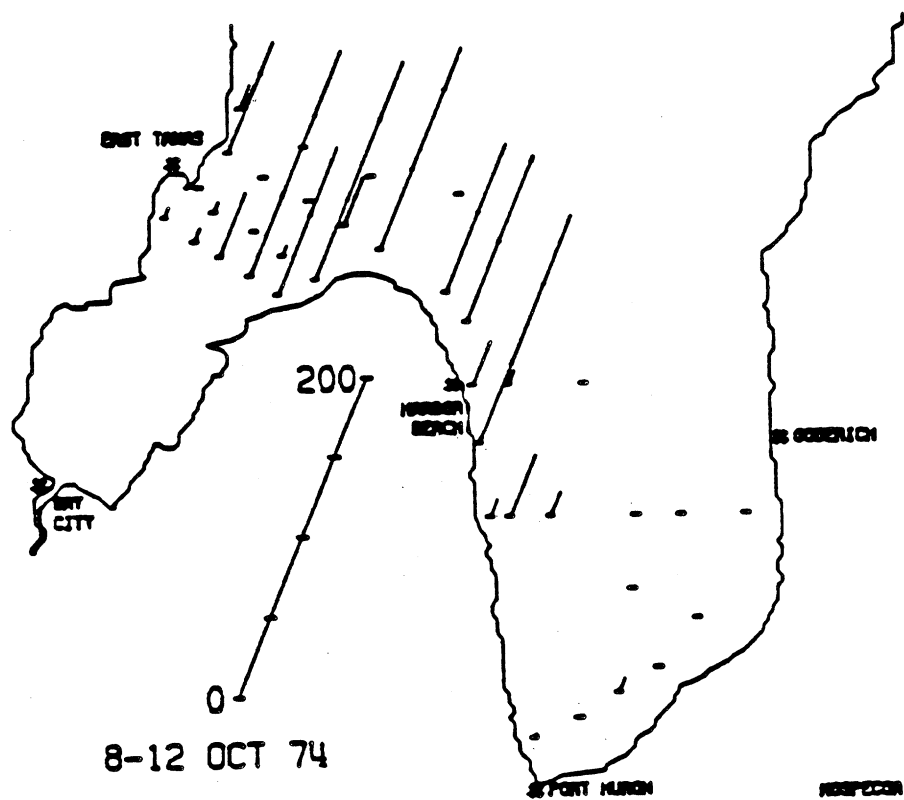


FIG. 101. Distribution and abundance (cells/mL) of Mougeotia sp. #1, October (A) and November (B), 1974.

reductions between years were Coelastrum microporum, Tetraedron minimum, and all Pediastrum species. Gloeocystis planctonica also showed declines in abundance, although the number of occurrences remained the same. This species was usually seen in highest abundance in the offshore waters, in contrast to the others discussed.

One green alga, Ankistrodesmus sp. #3, which may be an undescribed variety of A. falcatus, showed a significant increase ( $p < 0.05$ ) between 1974 and 1980. During October of both years (Figs. 102A and B), it was well distributed throughout the study area. However, in 1980 abundances were approximately twice those observed in 1974. In addition, another green algal group to show slight increases between years was Scenedesmus spp.

Crucigenia quadrata was found throughout the study area during both years with slightly elevated standing crops in the northern Saginaw Bay interface waters (Figs. 103A and B). This green alga showed little difference in abundance and occurrence between years.

Several eutrophic diatom species showed reductions in abundance between years; these primarily had their distributions centered in outer Saginaw Bay. Actinocyclus normanii fo. subsalsa was observed at fairly low densities in the spring and fall of 1974, with highest abundances observed in October (Fig. 104). During 1980, only one occurrence at extremely low abundance was observed in the spring at the southeastern corner of outer Saginaw Bay. During both years the only occurrences observed were in outer Saginaw Bay. Melosira granulata reached its greatest abundances during October of both years. In 1974, it was observed in outer Saginaw Bay, at stations south of Saginaw Bay, and lower abundances in the nearshore areas of the southern basin (Fig. 105A). During 1980, it was confined to outer Saginaw Bay (Fig. 105B).

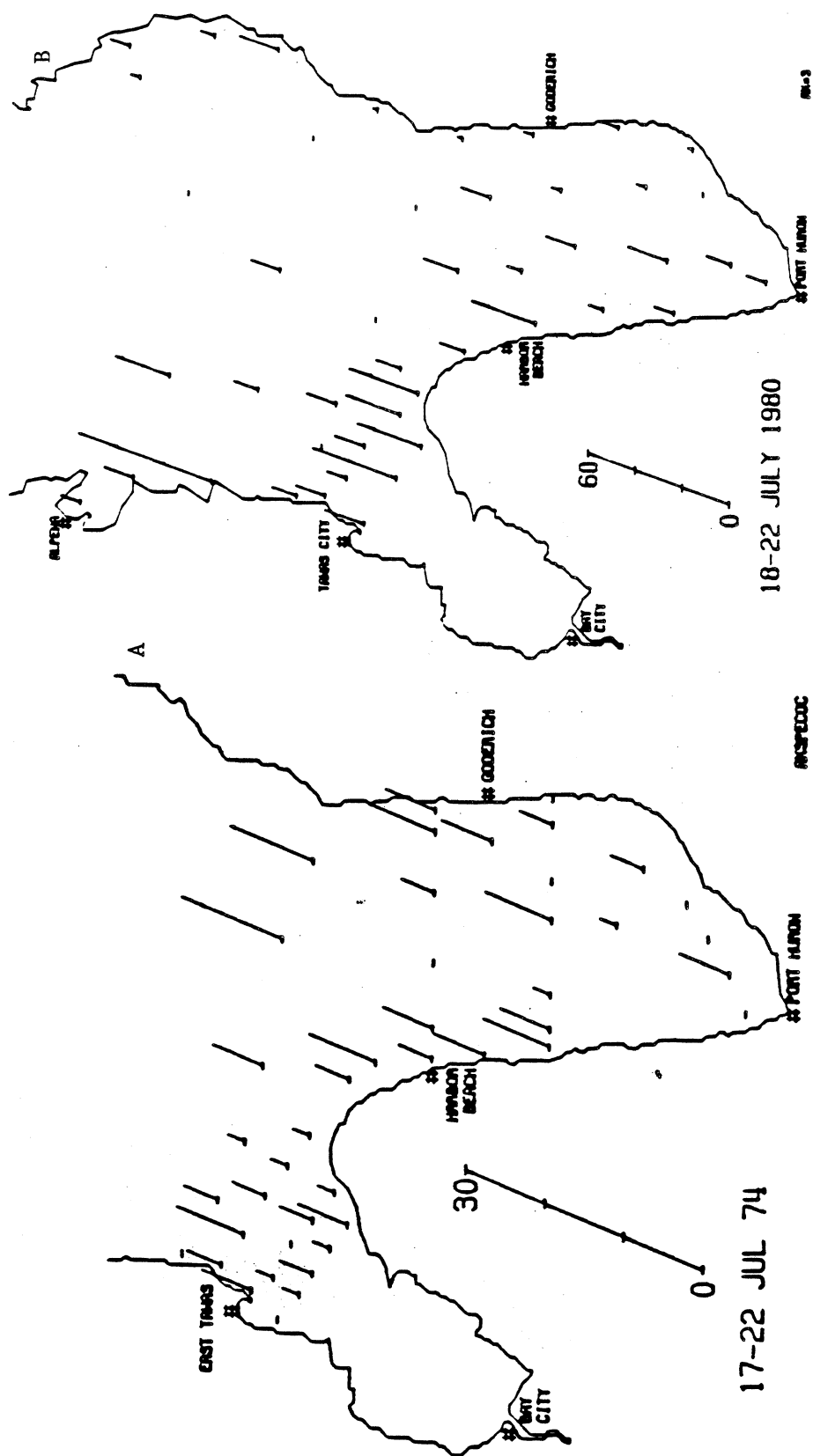


FIG. 102. Distribution and abundance (cells/mL) of *Ankistrodesmus* sp. #3, July 1974 (A) and 1980 (B).

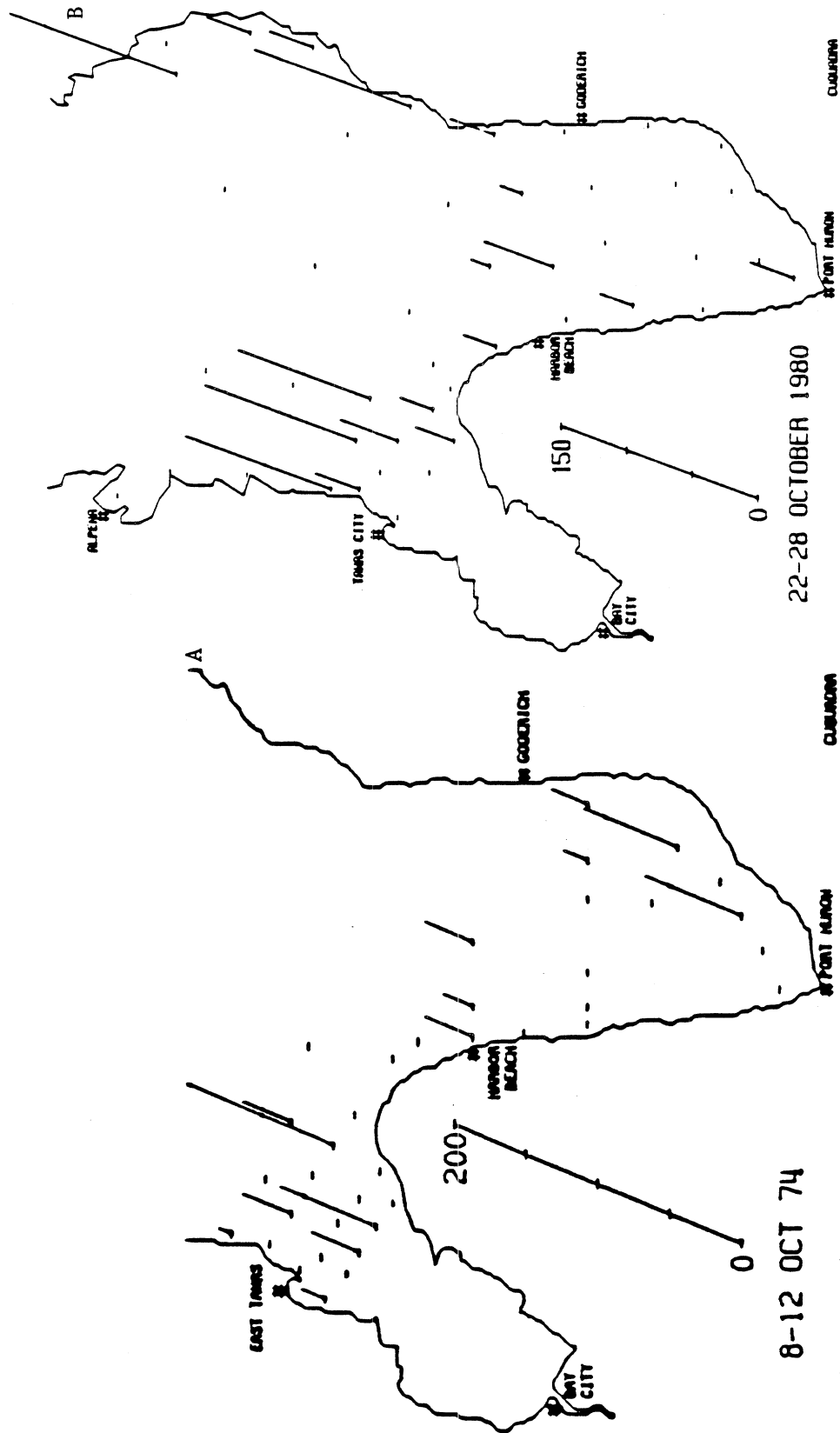


FIG. 103. Distribution and abundance (cells/mL) of *Crucigenia quadrata*, October (A) 1974 and 1980 (B).

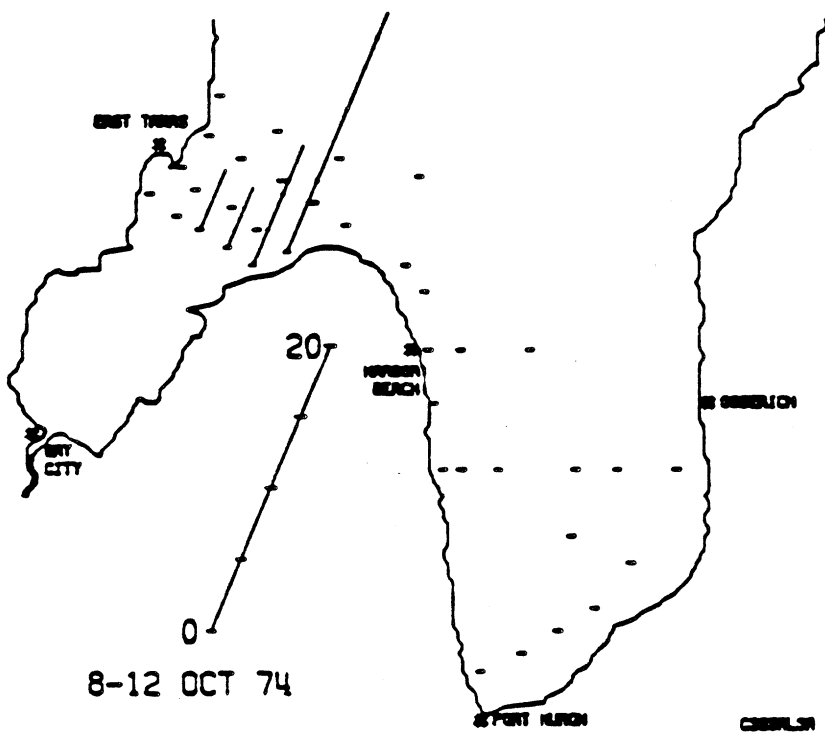


FIG. 104. Distribution and abundance (cells/mL) of *Actinocyclus normanii* fo. *subsalsa*, October 1974.

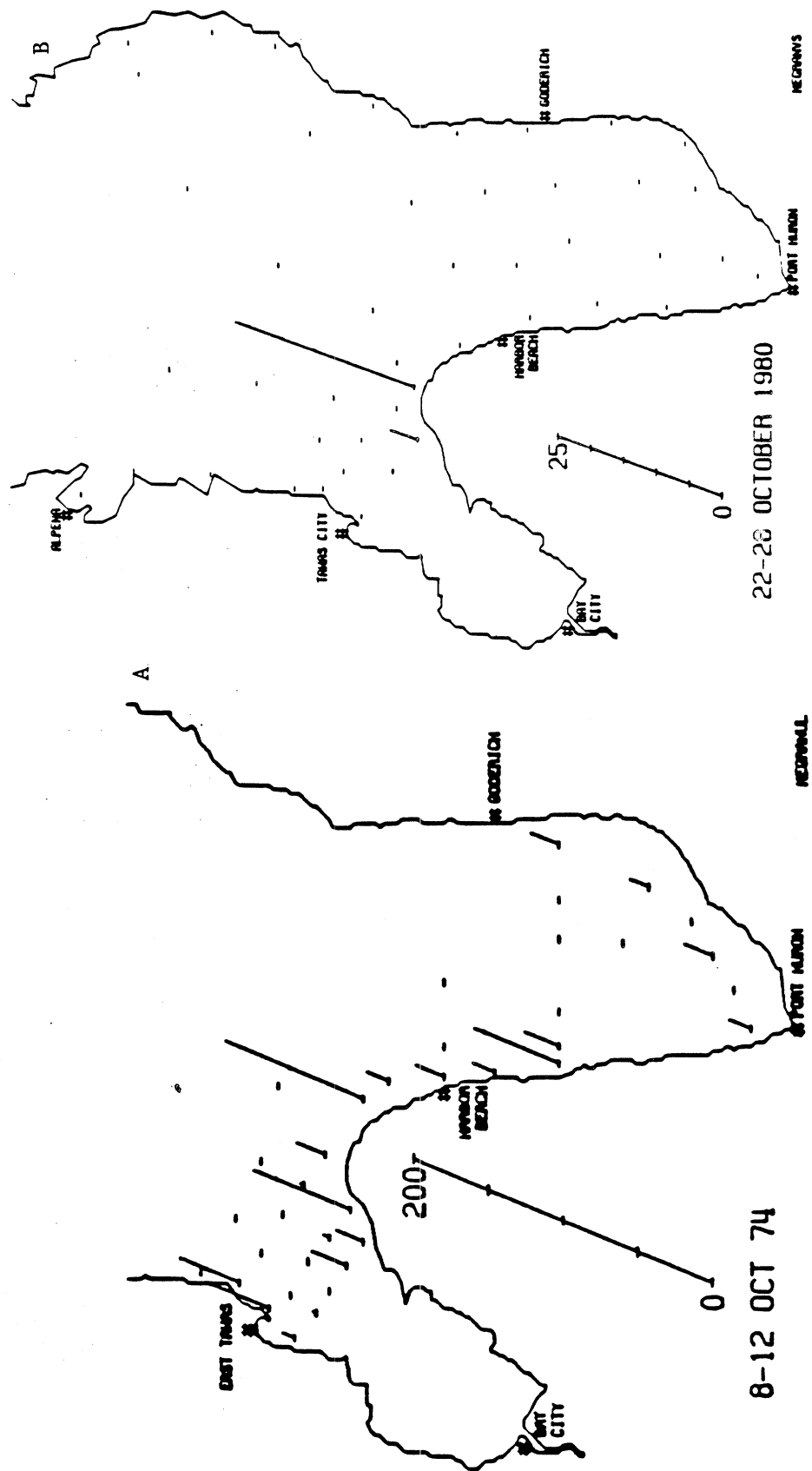


FIG. 105. Distribution and abundance (cells/mL) of *Melosira granulata*, October 1974 (A) and 1980 (B).

During the spring of both years, Stephanodiscus binderanus was generally observed in outer Saginaw Bay. However, during 1980, abundances were substantially reduced for this species (Figs. 106A and B).

Fragilaria capucina was typically associated with Saginaw Bay during both years but showed a seasonal shift in peak abundance. During June of both years, Fragilaria capucina showed highest abundances in outer Saginaw Bay, with decreasing densities southward along the U.S. coastal area (Figs. 107A and B). During June 1980, abundances were substantially reduced compared to June 1974. During October of both years (Figs. 108A and B), distribution patterns of Fragilaria capucina were similar, but when comparing these months, higher standing crops were observed in 1980 than during 1974, exhibiting a seasonal shift in peak abundance. Other eutrophic species showing reductions between years were Cyclotella meneghiniana, Diatoma tenue var. elongatum, and Stephanodiscus tenuis.

Numerous offshore species also showed declines in 1980 compared to 1974. Of particular concern is the genus Cyclotella, which is typically representative of the oligotrophic flora in the Laurentian Great Lakes. Cyclotella comta exhibited significant reductions ( $p < 0.05$ ) in abundance and distribution between years in offshore waters of the central and southern basins (Figs. 109A and B). Similarly, Cyclotella stelligera (Figs. 110A and B) showed significantly lower ( $p < 0.05$ ) numbers, particularly in the southern basin. However, in 1980, elevated abundances were observed in the Saginaw Bay interface region compared to the remainder of the study area. This condition was not observed in 1974 when it was distinctly lower in outer Saginaw Bay. Cyclotella ocellata and Cyclotella michiganiana were significantly reduced ( $p < 0.05$ ) in 1980. Cyclotella ocellata (Figs. 111A and B) exhibited lower

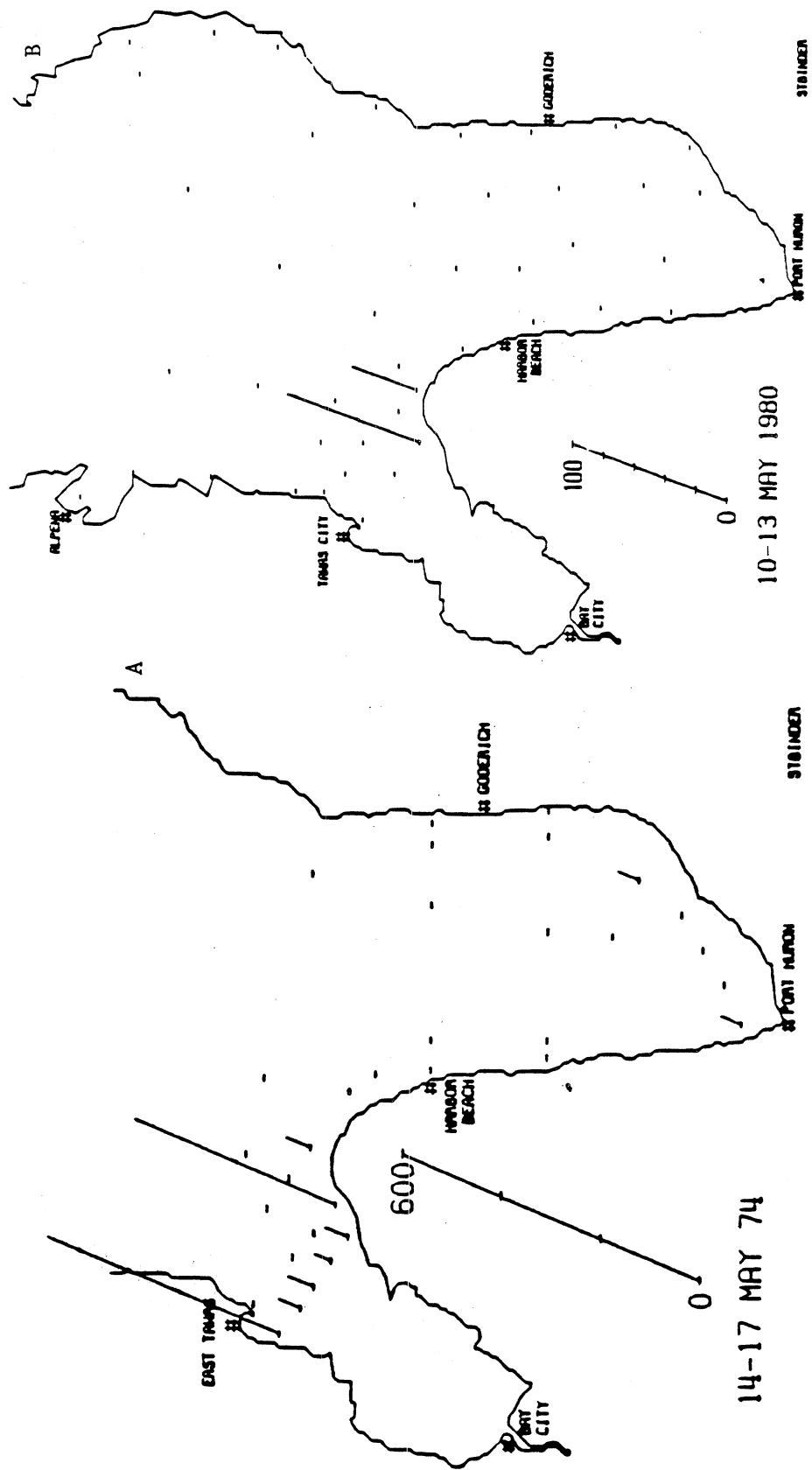


FIG. 106. Distribution and abundance (cells/mL) of *Stephanodiscus binderanus*, May 1974 (A) and 1980 (B).

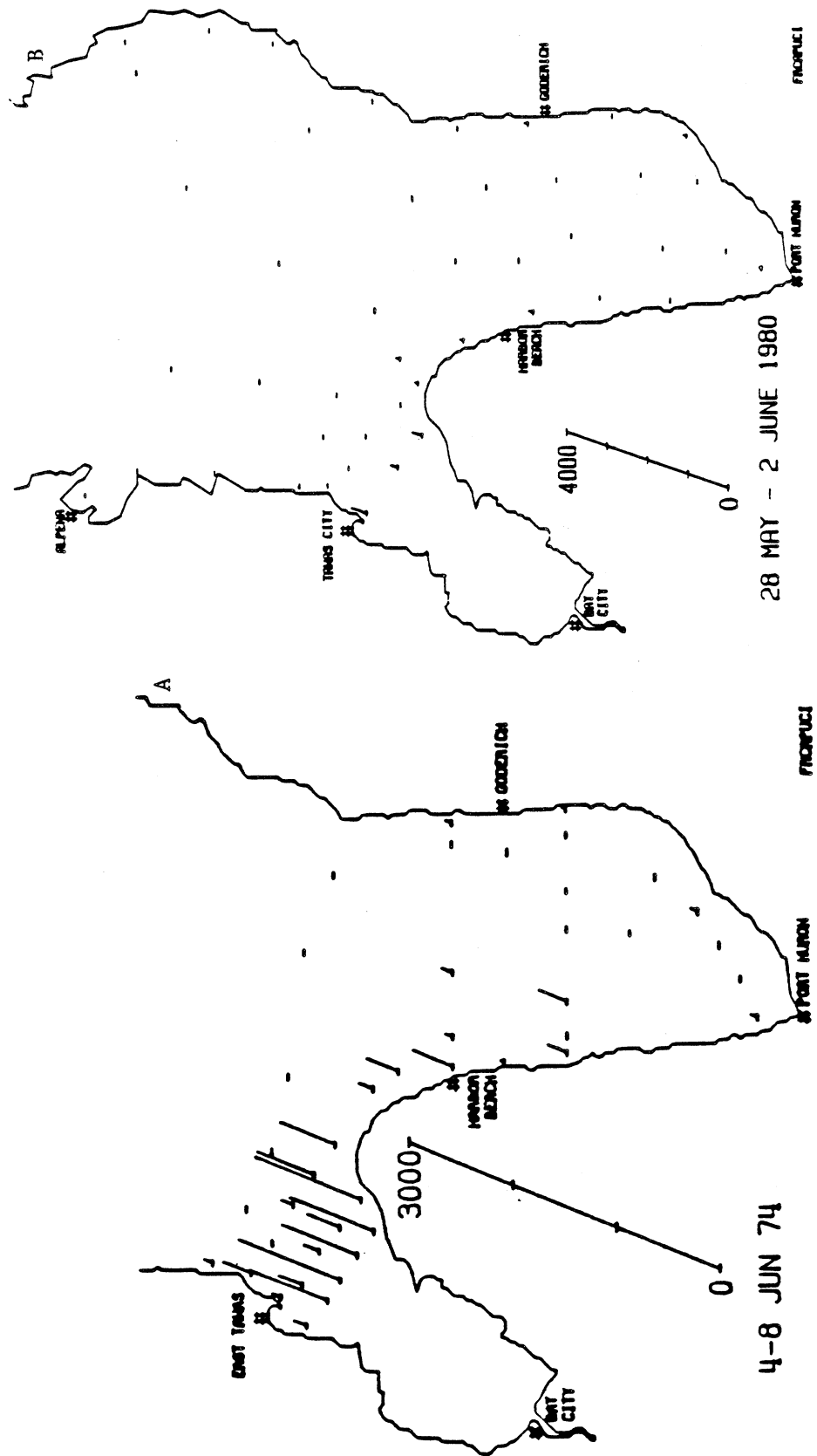


FIG. 107. Distribution and abundance (cells/mL) of *Fragilaria capucina*, June 1974 (A) and 1980 (B).

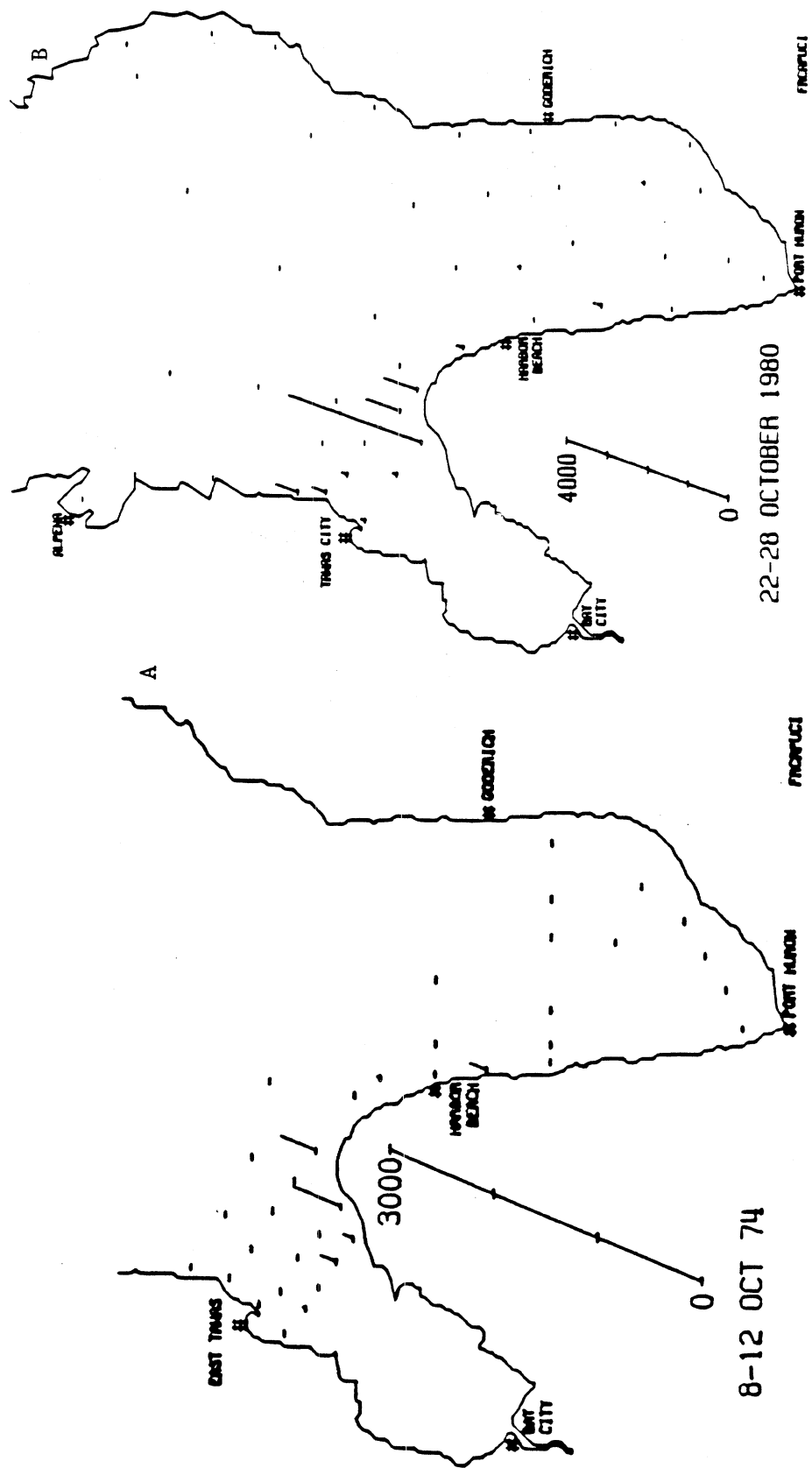


FIG. 108. Distribution and abundance (cells/mL) of *Fragilaria capucina*, October 1974 (A) and 1980 (B).

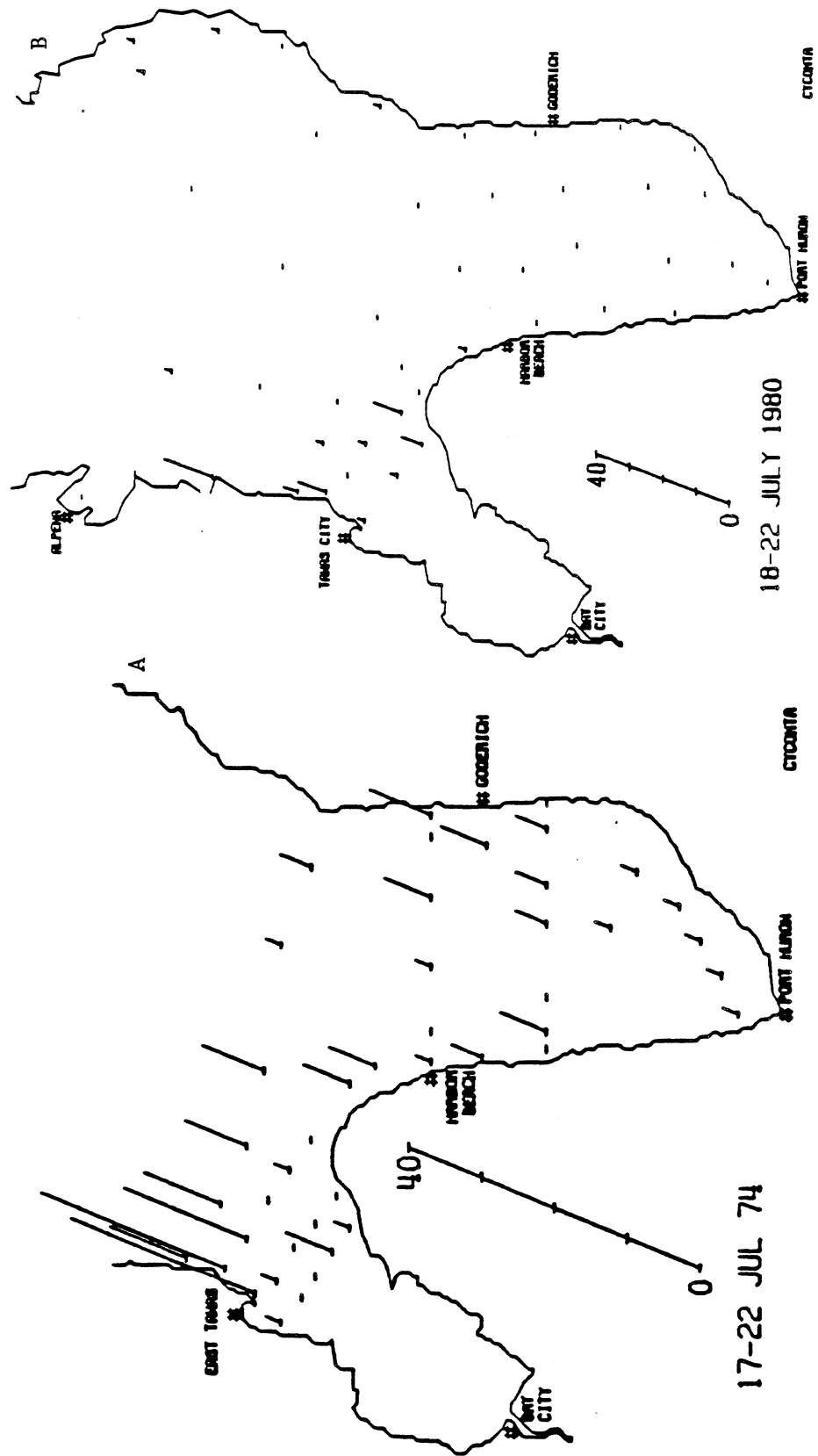


FIG. 109. Distribution and abundance (cells/mL) of *Cyclotella comta*, October 1974 (A) and 1980 (B).

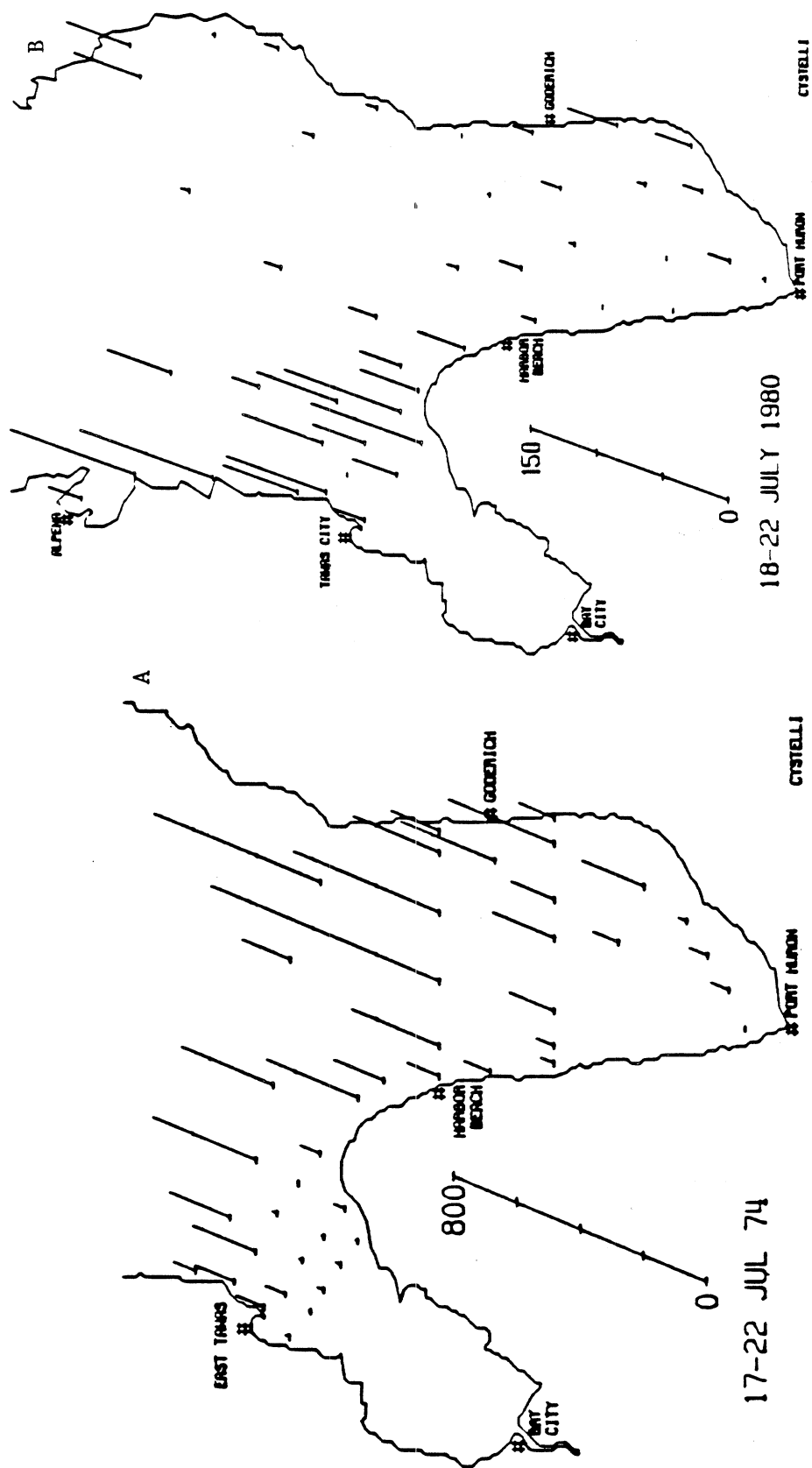


FIG. 110. Distribution and abundance (cells/mL) of *Cyclotella stelligera*, July 1974 (A) and 1980 (B).

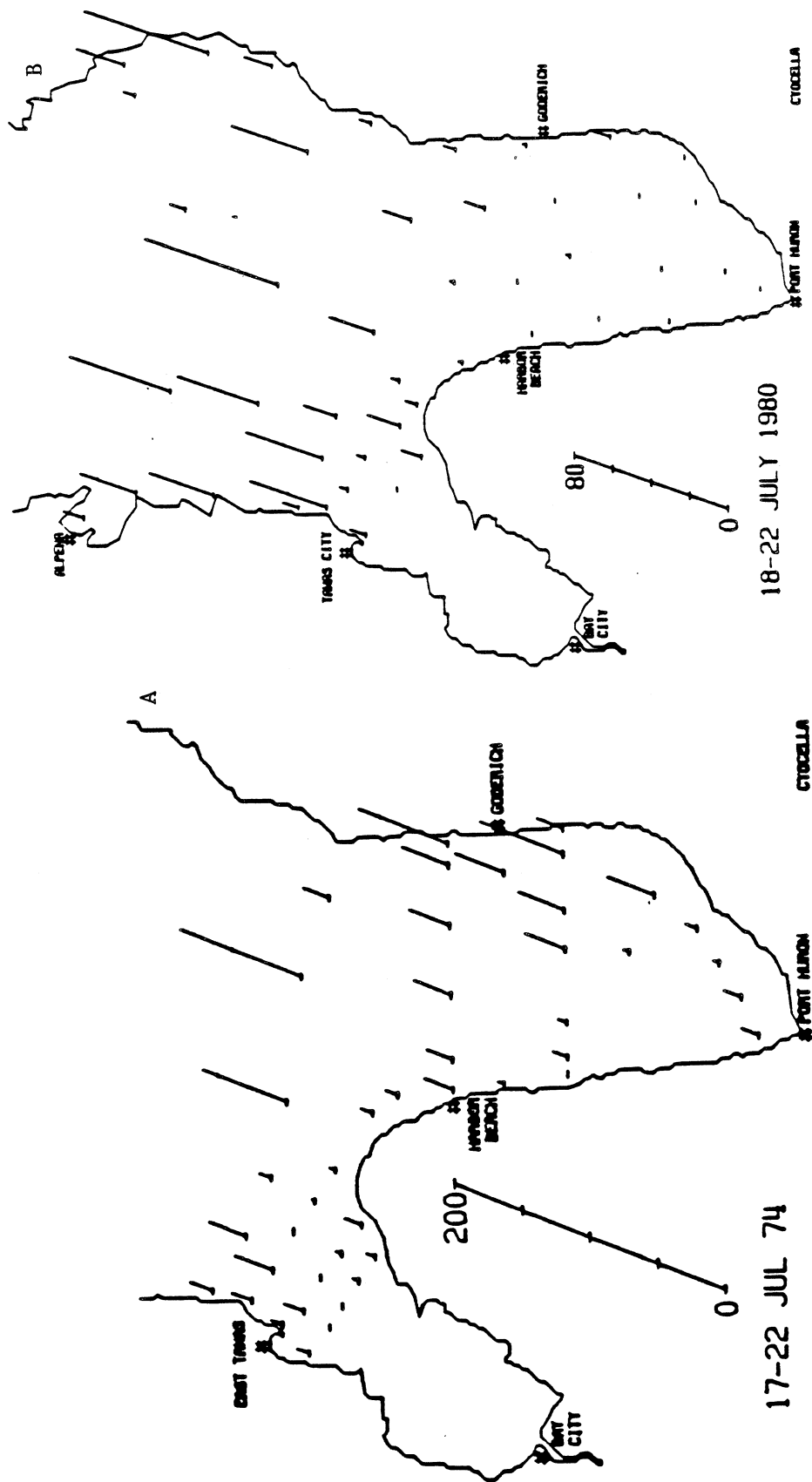


FIG. 111. Distribution and abundance (cells/mL) of *Cyclotella ocellata*, July 1974 (A) and 1980 (B).

abundance and occurrence in the southern basin during 1980 but still maintained similar standing crops in the central basin. Cyclotella michiganiana (Figs. 112A and B) had much lower abundances and fewer occurrences in the southern basin in 1980. Two other Cyclotella species, C. operculata and C. sp. #5 also significantly decreased ( $p < 0.05$ ) in 1980.

Melosira islandica was slightly less abundant in 1980 (Figs. 113A and B), but was particularly reduced in the Canadian nearshore zone of the southern basin. During 1974, large standing crops were observed shoreward of the spring thermal bar. Large abundances were not observed during thermal bar conditions in 1980. Synedra filiformis also exhibited distinctively lower densities in 1980 (Figs. 114A and B). Although it was still widely distributed during 1980, abundances were significantly reduced ( $p < 0.05$ ) in the offshore waters of the southern and central basins. Other taxa showing reductions in the offshore waters between years were Stephanodiscus transilvanicus, Nitzschia acicularis, Synedra ostenfeldii, S. ulna var. chaseana, Fragilaria intermedia var. fallax, and Rhizosolenia eriensis.

Two eurytopic diatom species, Fragilaria crotonensis (Figs. 115A and B) and Tabellaria fenestrata (Figs. 116A and B), were less abundant in 1980 compared to 1974. However, another eurytopic species, Asterionella formosa (Figs. 117A and B), showed lower mean cell densities in 1980, but remained fairly constant during its peak abundance in May between years.

Benthic taxa that were typically abundant in nearshore zones showed considerable declines in 1980. Species of the genera Achnanthes, Amphora, Cocconeis, Cymbella, Fragilaria and Navicula were substantially reduced.

Cyclotella comensis increased significantly ( $p < 0.05$ ) in abundance between 1974 and 1980 (Figs. 118A and B) and was widely distributed during peak

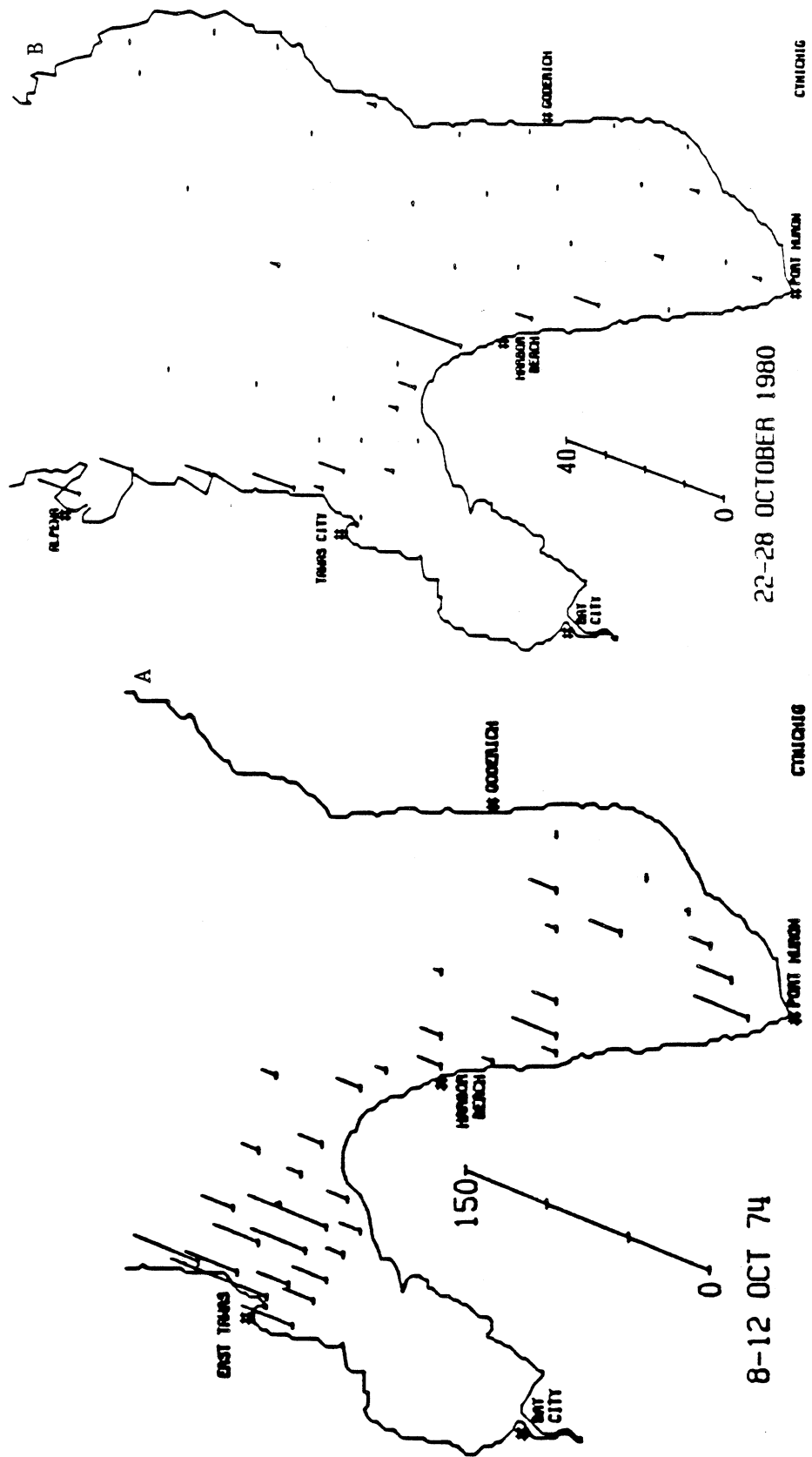


FIG. 112. Distribution and abundance (cells/mL) of *Cyclotella michiganiana*, October 1974 (A) and 1980 (B).

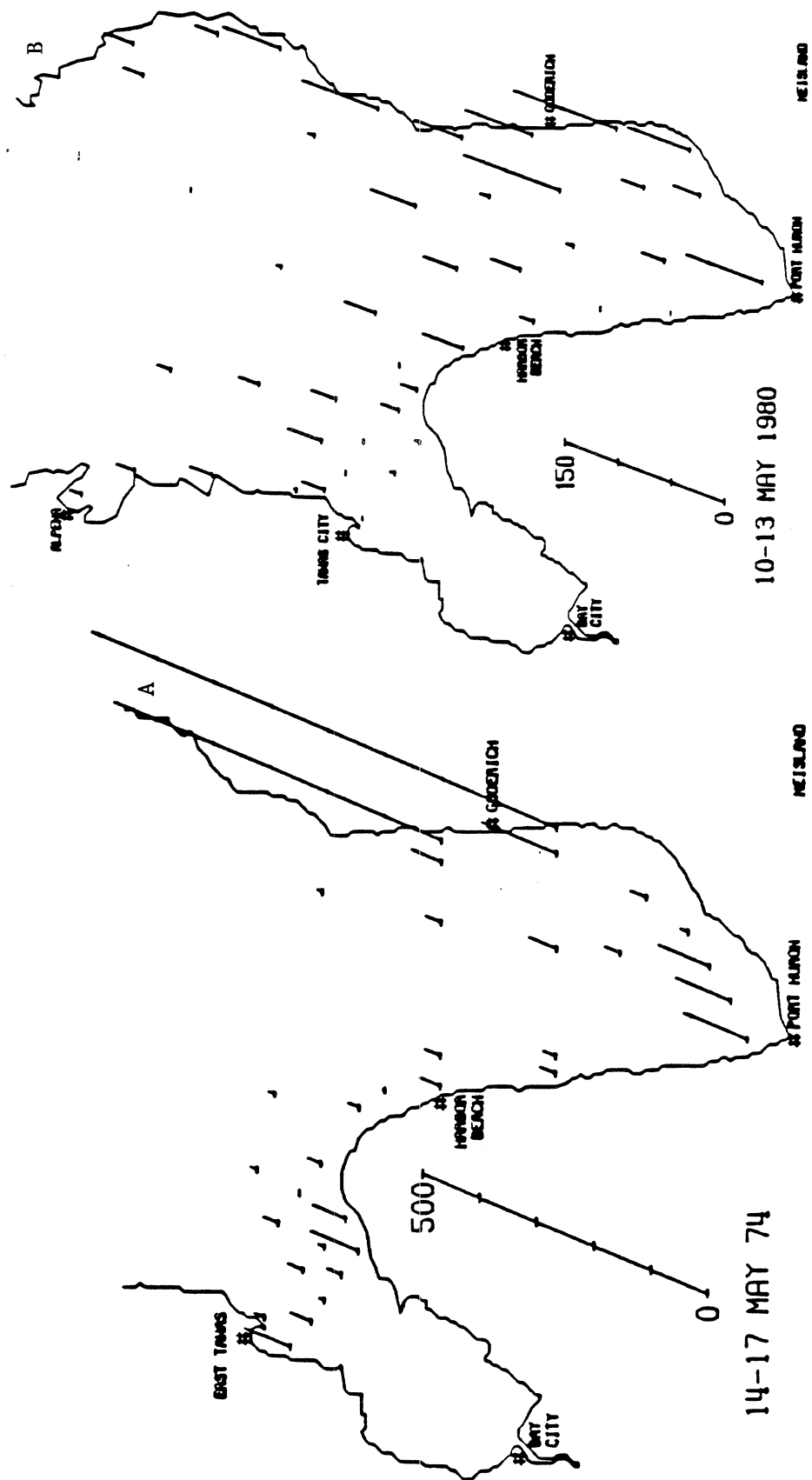


FIG. 113. Distribution and abundance (cells/mL) of Melosira islandica, May 1974 (A) and 1980 (B).

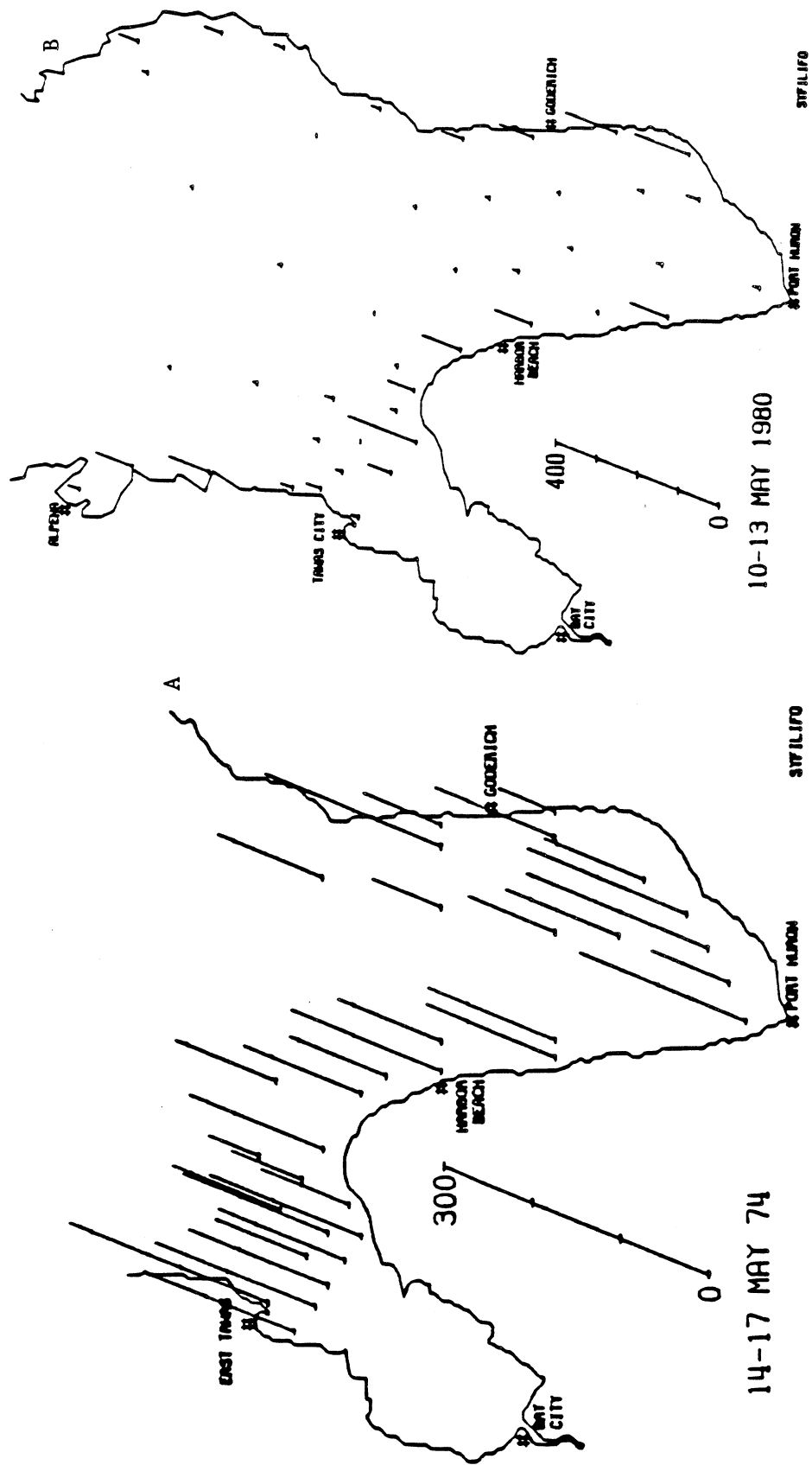


FIG. 114. Distribution and abundance (cells/mL) of *Synedra filiformis*, May 1974 (A) and 1980 (B).

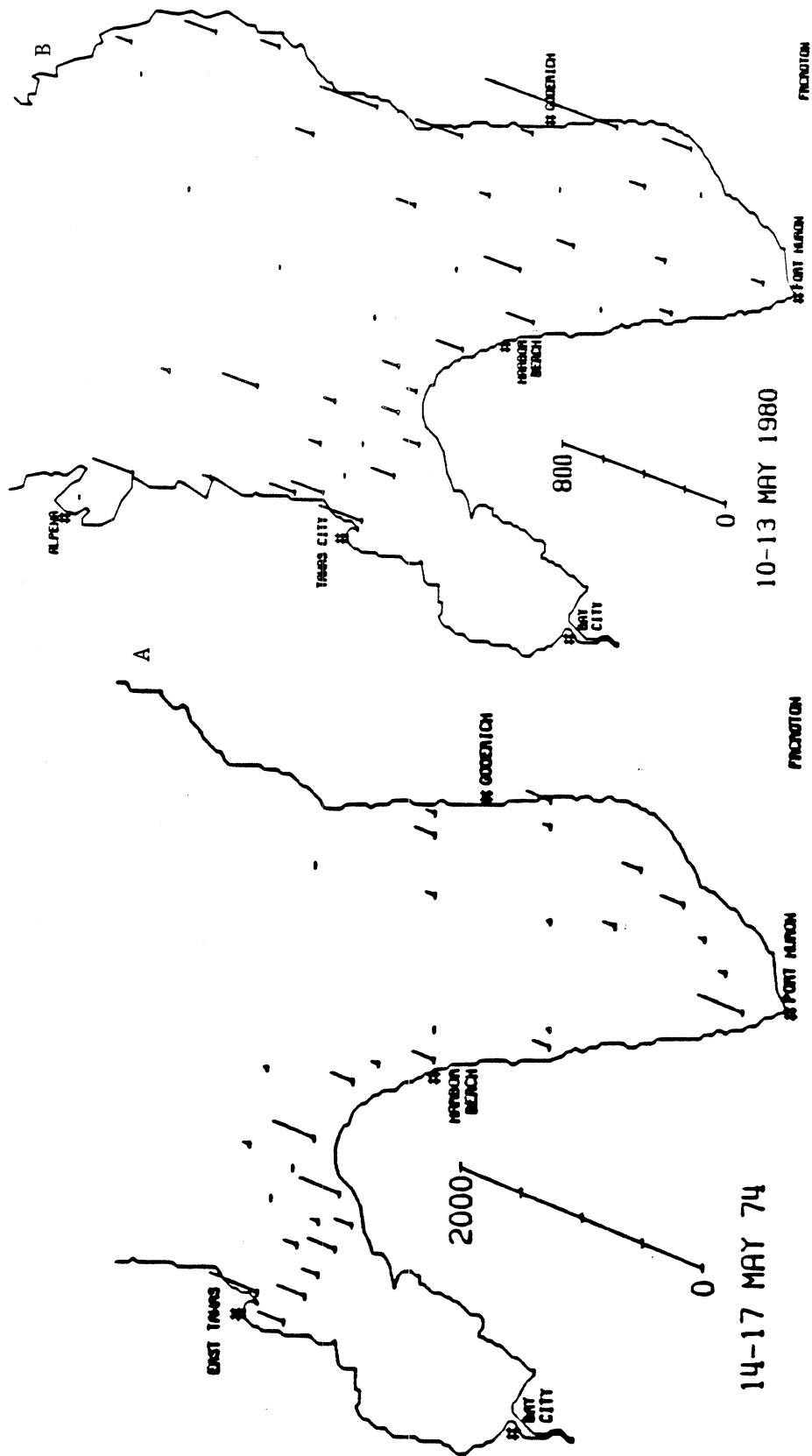


FIG. 115. Distribution and abundance (cells/mL) of *Fragilaria crotonensis*, May 1974 (A) and 1980 (B).

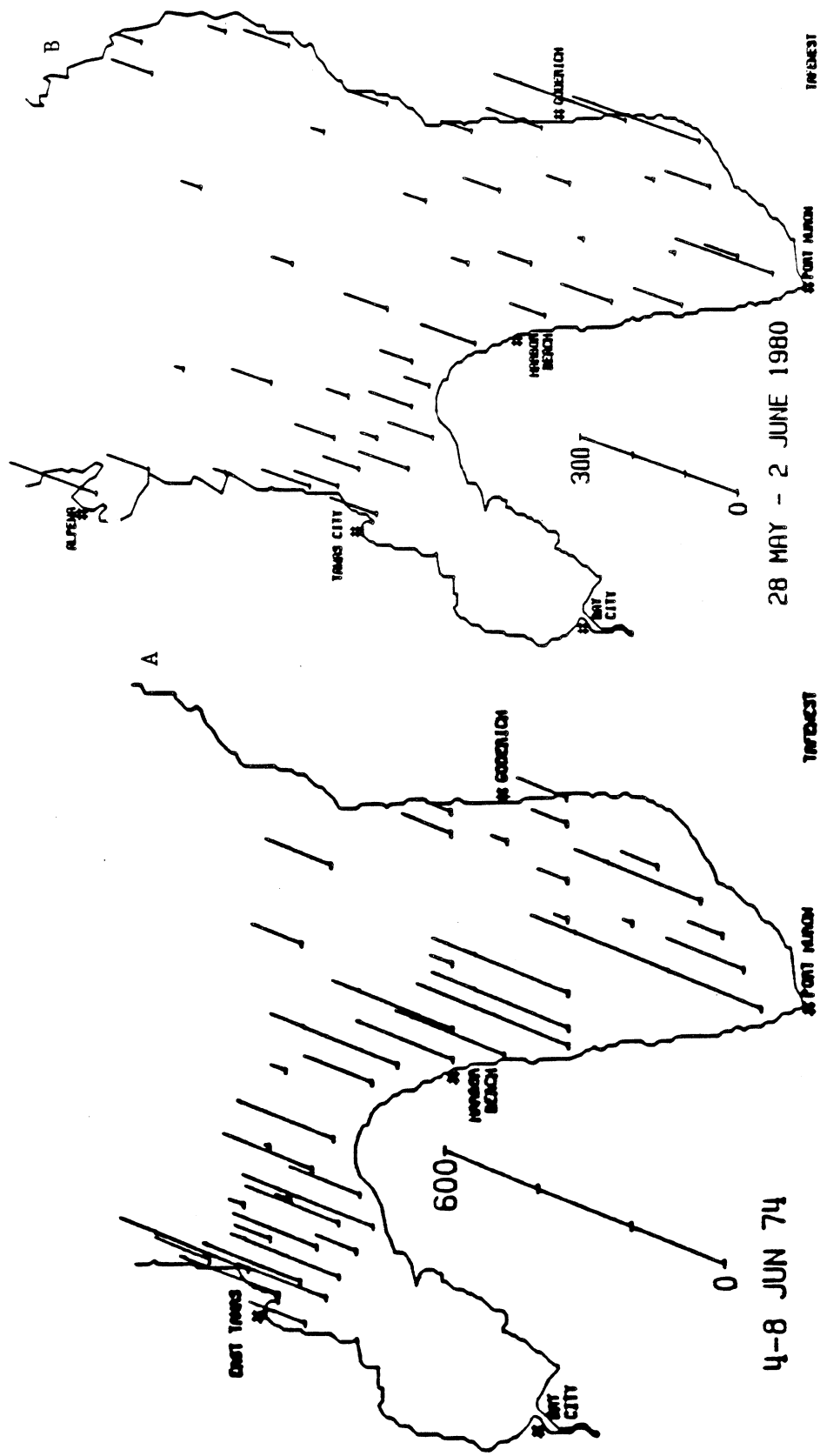


FIG. 116. Distribution and abundance (cells/mL) of Tabellaria fenestrata, June 1974 (A) and 1980 (B).

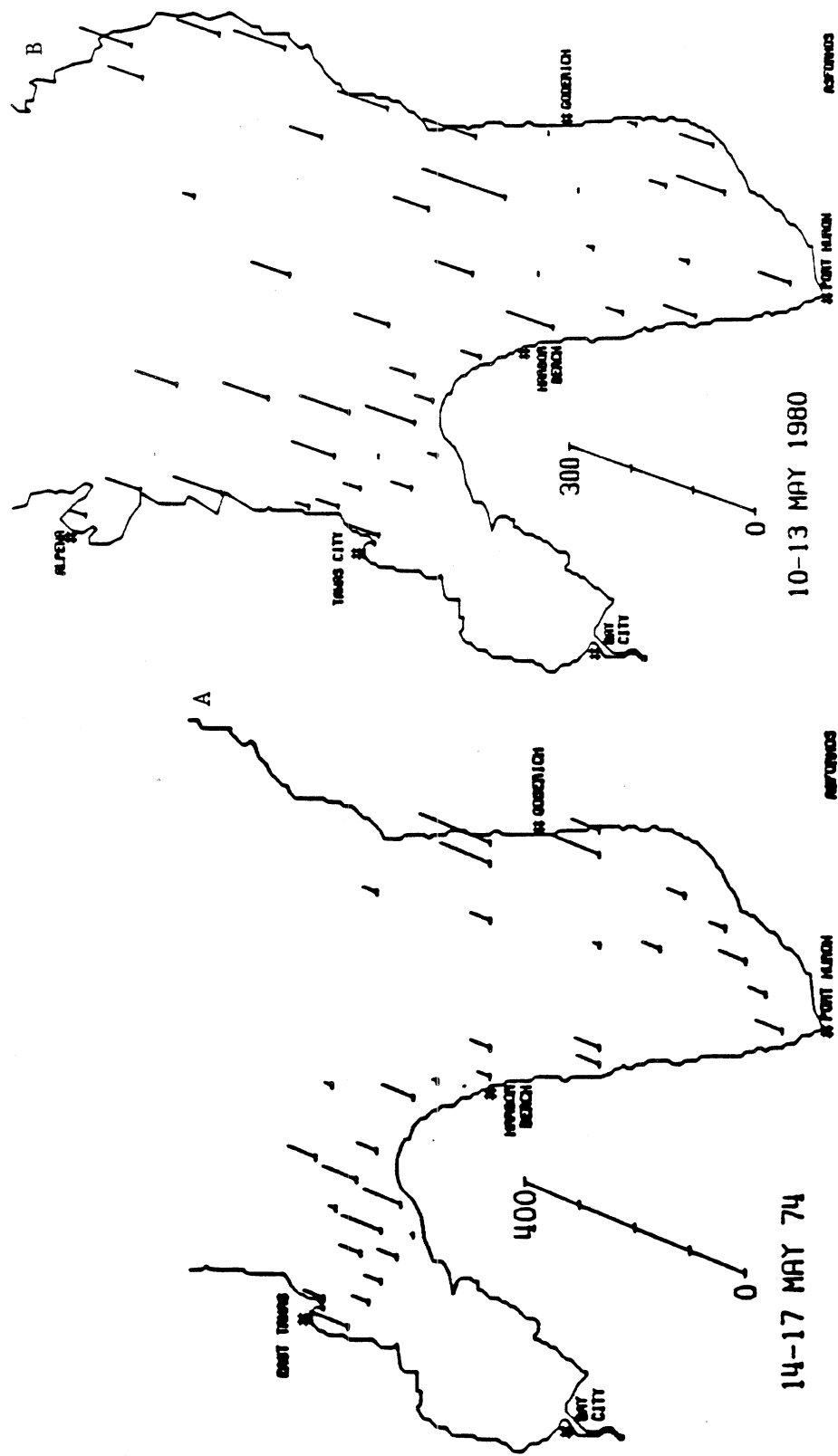


FIG. 117. Distribution and abundance (cells/mL) of *Asturionella formosa*, May 1974 (A) and 1980 (B).

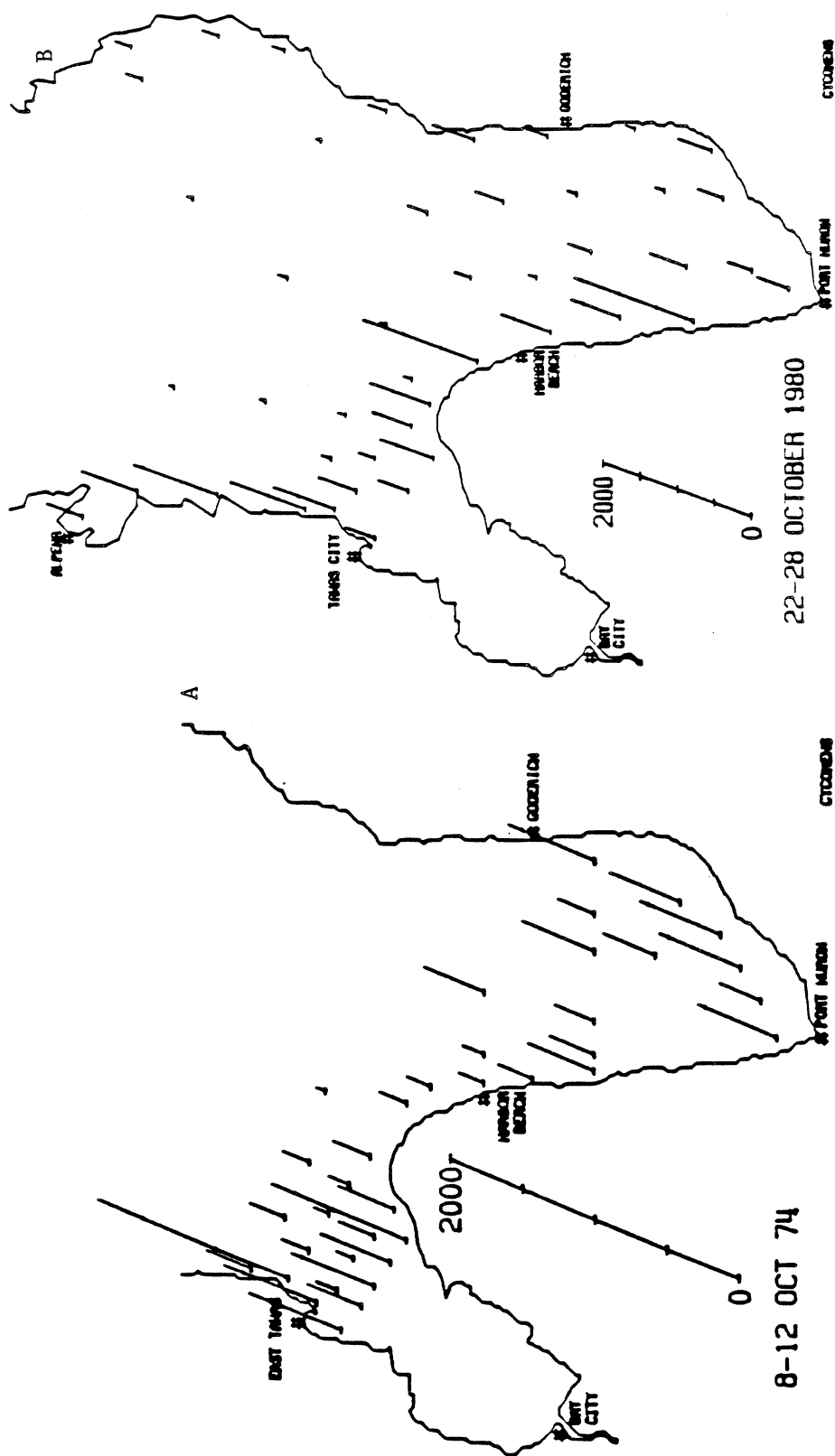


FIG. 118. Distribution and abundance (cells/mL) of *Cyclotella comensis*, October 1974 (A) and 1980 (B).

abundance periods in the fall of both years. However, it also occurred during the spring of 1980 in moderate densities compared to very low abundances in the spring of 1974. Cyclotella pseudostelligera also increased significantly ( $p < 0.05$ ) in abundance in 1980 and greatly extended its distribution, especially in the southern basin.

Chrysophytes increased in the study area between 1974 and 1980, primarily during the spring months. Several taxa that were not observed in 1974, or were observed sporadically and placed in the undetermined category, sharply increased in 1980. Populations of Chrysococcus rufescens, Kephyrion spp., Monochrysis aphanaster, and Spiniferomonas spp. were common during 1980.

Dinobryon divergens increased significantly ( $p < 0.05$ ) between 1974 and 1980. It especially exhibited higher abundances and a wider occurrence in the early spring of 1980 compared to 1974 (Figs. 119A and B). D. divergens was present in moderate abundances during all sampling periods in 1980, but during 1974 it showed sporadic peaks in late June, July, and November.

Ochromonas sp. #2 increased significantly ( $p < 0.05$ ) between years. It was an order of magnitude greater in 1980, particularly in the spring months. Ochromonas sp. #2 was widely distributed throughout the entire study area during both years (Figs. 120A and B).

Chrysococcus dokidophorus and Chrysosphaerella longispina populations maintained similar standing crops between years. Chrysococcus dokidophorus was well distributed throughout the study area during both years (Figs. 121A and B), although it occurred in a more uniform distribution in 1980. Chrysosphaerella longispina usually occurs in large, motile colonies which produces large errors associated with abundance estimates and makes distributions patterns appear irregular (Figs. 122A and B). Highest

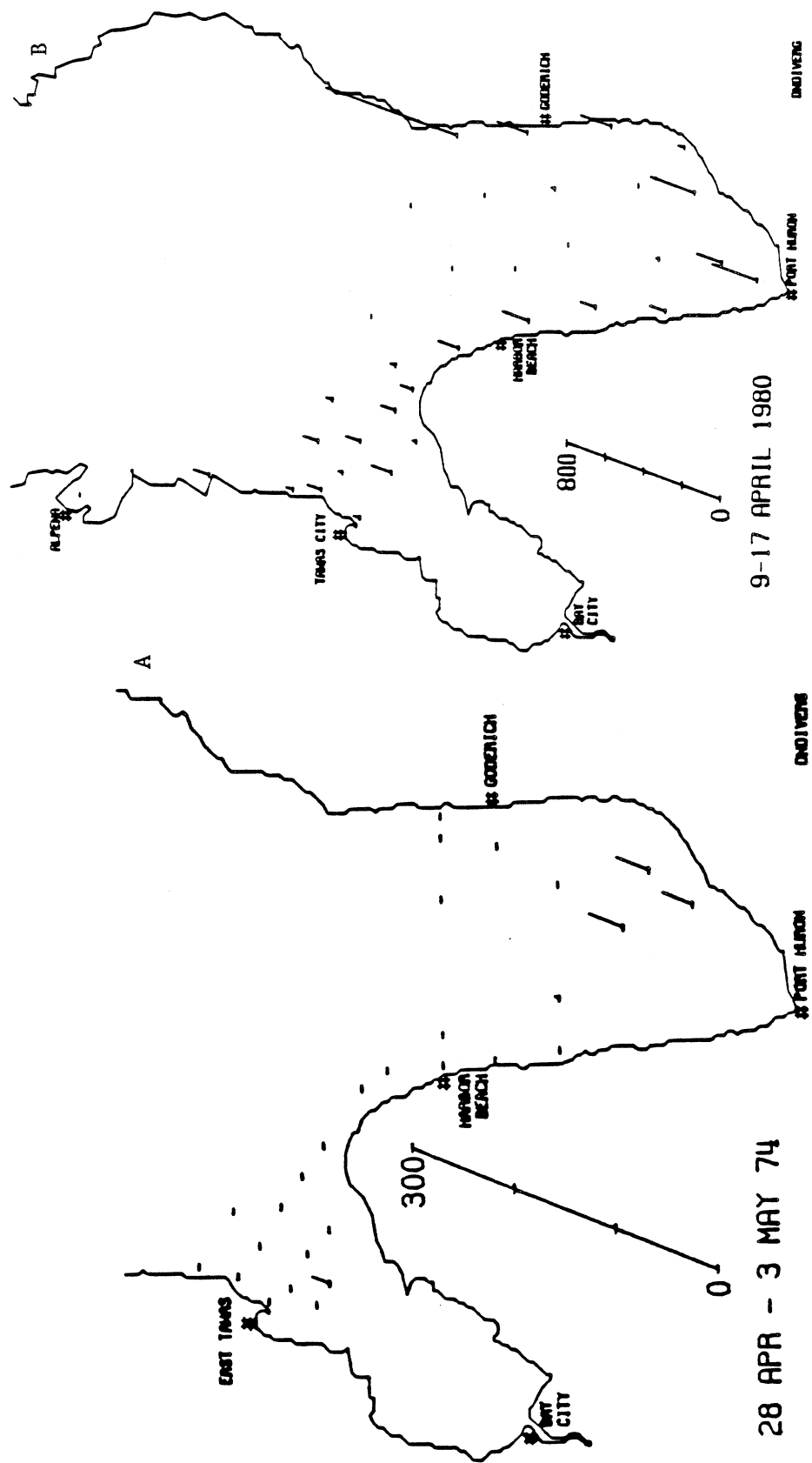


FIG. 119. Distribution and abundance (cells/mL) of *Dinobryon divergens*, April 1974 (A) and 1980 (B).

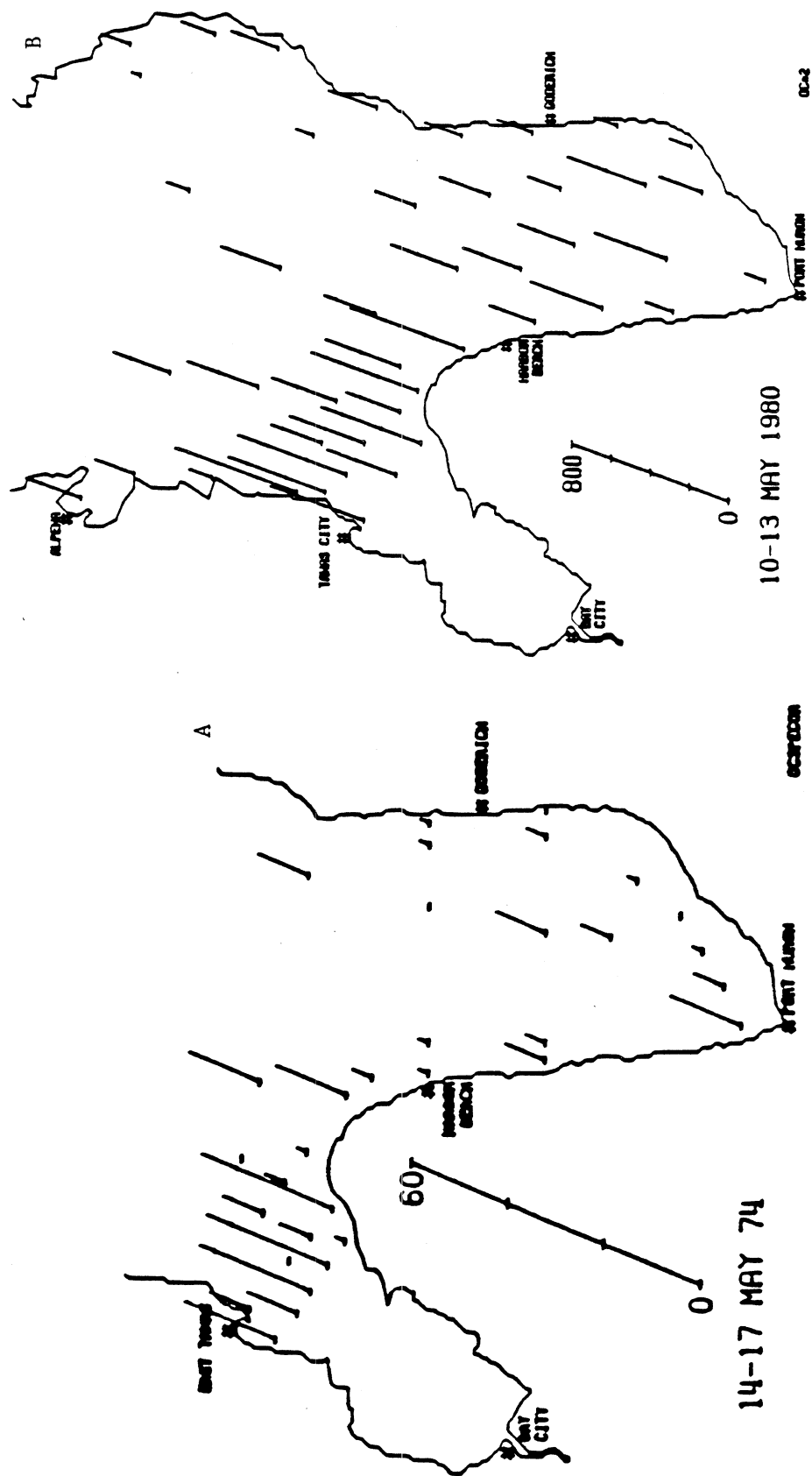


FIG. 120. Distribution and abundance (cells/mL) of *Ochromonas* sp. #2, May 1974 (A) and 1980 (B).

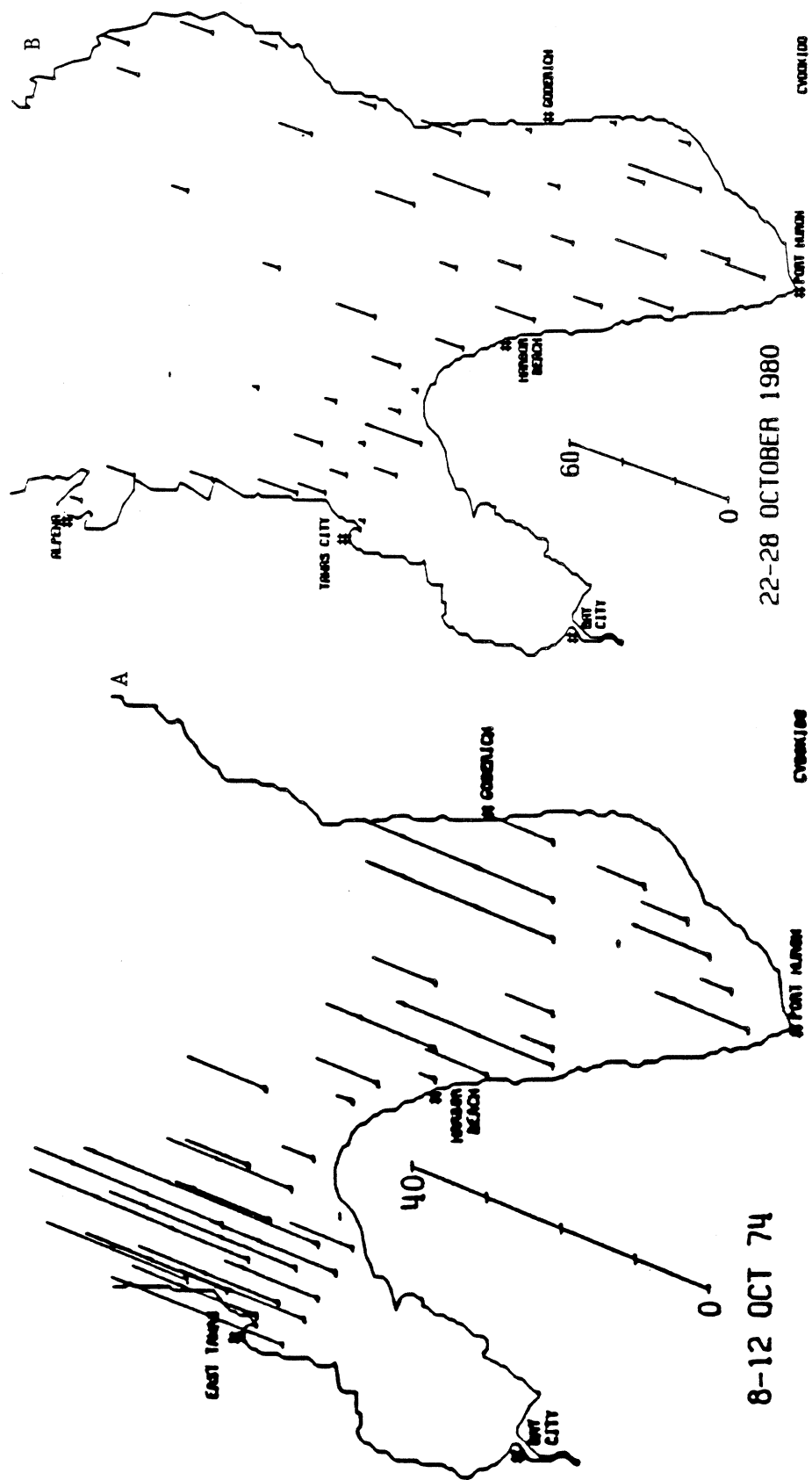


FIG. 121. Distribution and abundance (cells/mL) of *Chrysococcus dokidophorus*, October 1974 (A) and 1980 (B).

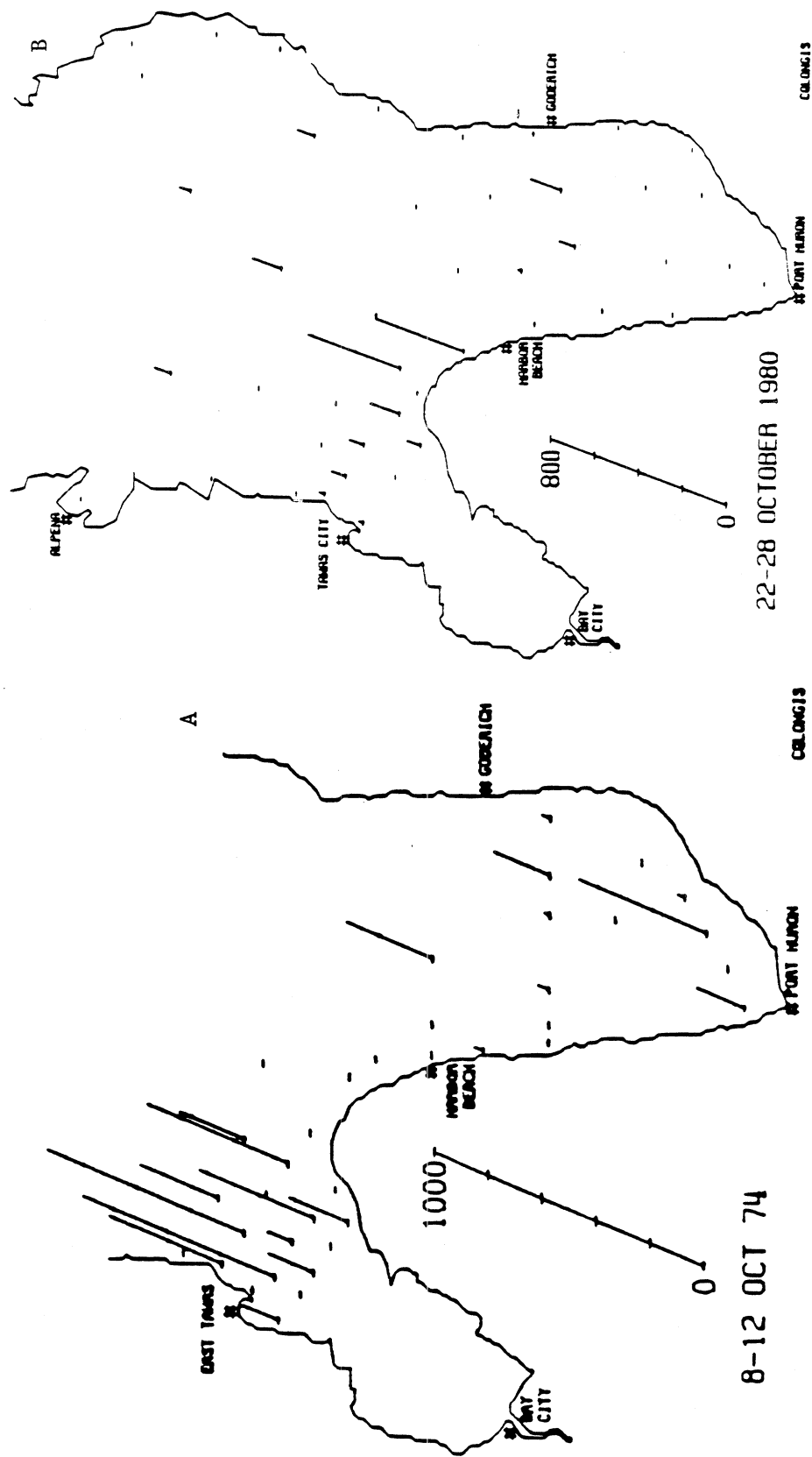


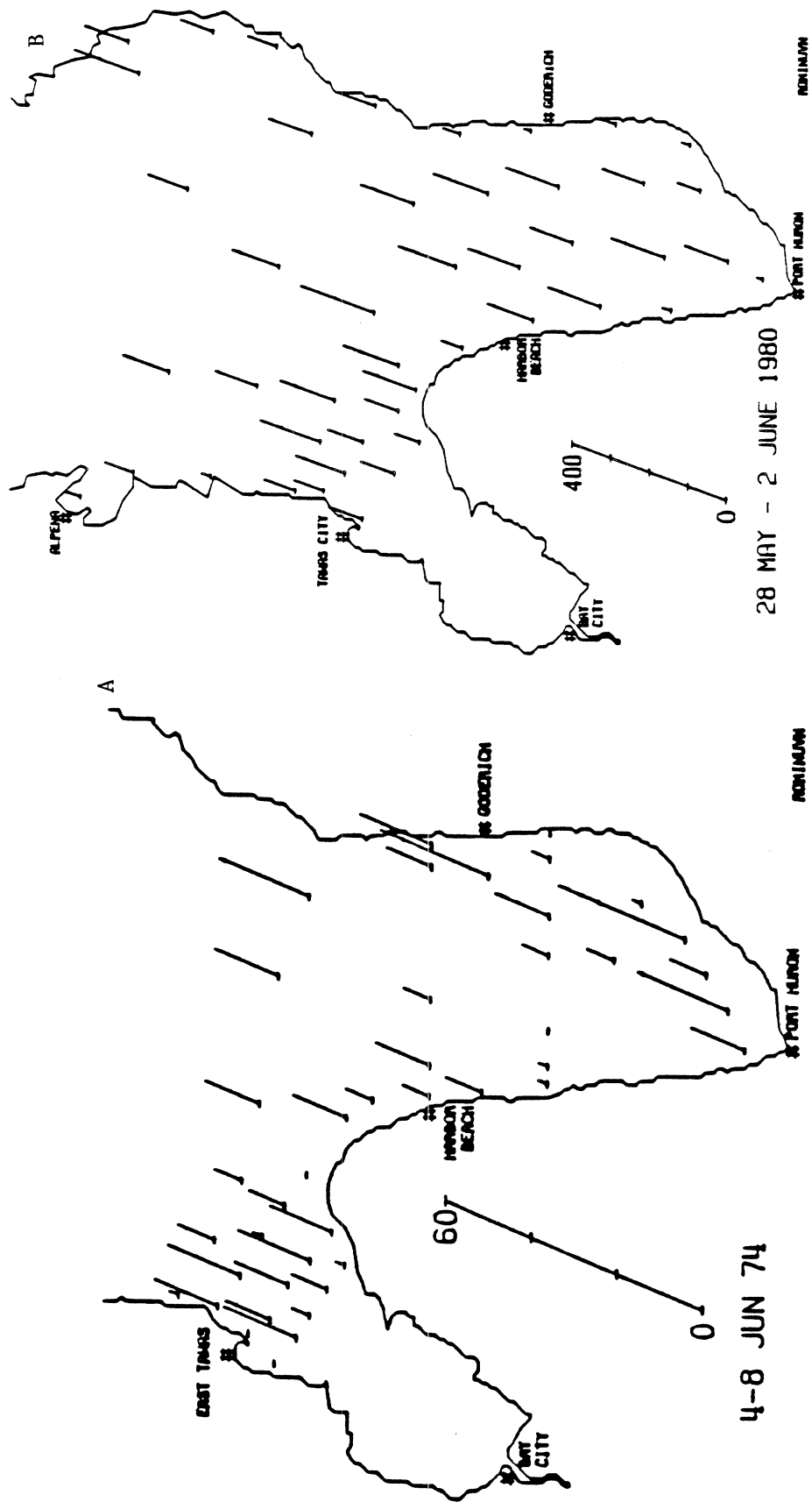
FIG. 122. Distribution and abundance (cells/mL) of *Chrysosphaerella longispina*, October 1974 (A) and 1980 (B).

abundances during both years were typically centered in the Saginaw Bay interface region. Mean abundance was slightly lower during 1980, but a similar number of occurrences was observed in each year.

Cryptomonads were widely distributed in southern Lake Huron during 1974 and 1980. However, cryptomonads substantially increased in abundance, particularly during the spring between 1974 and 1980. Rhodomonas minuta var. nannoplanctica and R. minuta significantly increased ( $p < 0.05$ ) in 1980. Rhodomonas minuta also showed a 3-fold increase in occurrence, whereas R. minuta var. nannoplanctica exhibited a similar number of occurrences. During 1974, Rhodomonas minuta var. nannoplanctica showed high abundances in outer Saginaw Bay and in the lower portions of the central and southern basins (Fig. 123A). In 1980, its distribution was uniform in the study area (Fig. 123B) but at abundances nearly an order of magnitude higher than during 1974.

Chroomonas spp. were sporadically observed during 1974 and were usually placed in the undetermined flagellate category. However, in 1980, members of the genus were much more common and accounted for a large portion of cryptomonad increases during 1980.

The genus Cryptomonas was better represented in 1980 than during 1974 and showed a large increase between years. More populations were identified to the species level, although undetermined Cryptomonas species accounted for a large increase in cryptomonad abundance during 1980. However, one common cryptomonad, Cryptomonas ovata, showed a significant decrease ( $p < 0.05$ ) in 1980. During 1974, it was distributed throughout the study area with highest abundances in outer Saginaw Bay (Fig. 124A). In 1980, Cryptomonas ovata was



123. Distribution and abundance (cells/mL) of *Rhodomonas minuta* var. *nanoplantica*, June 1974 (A) and 1980 (B).

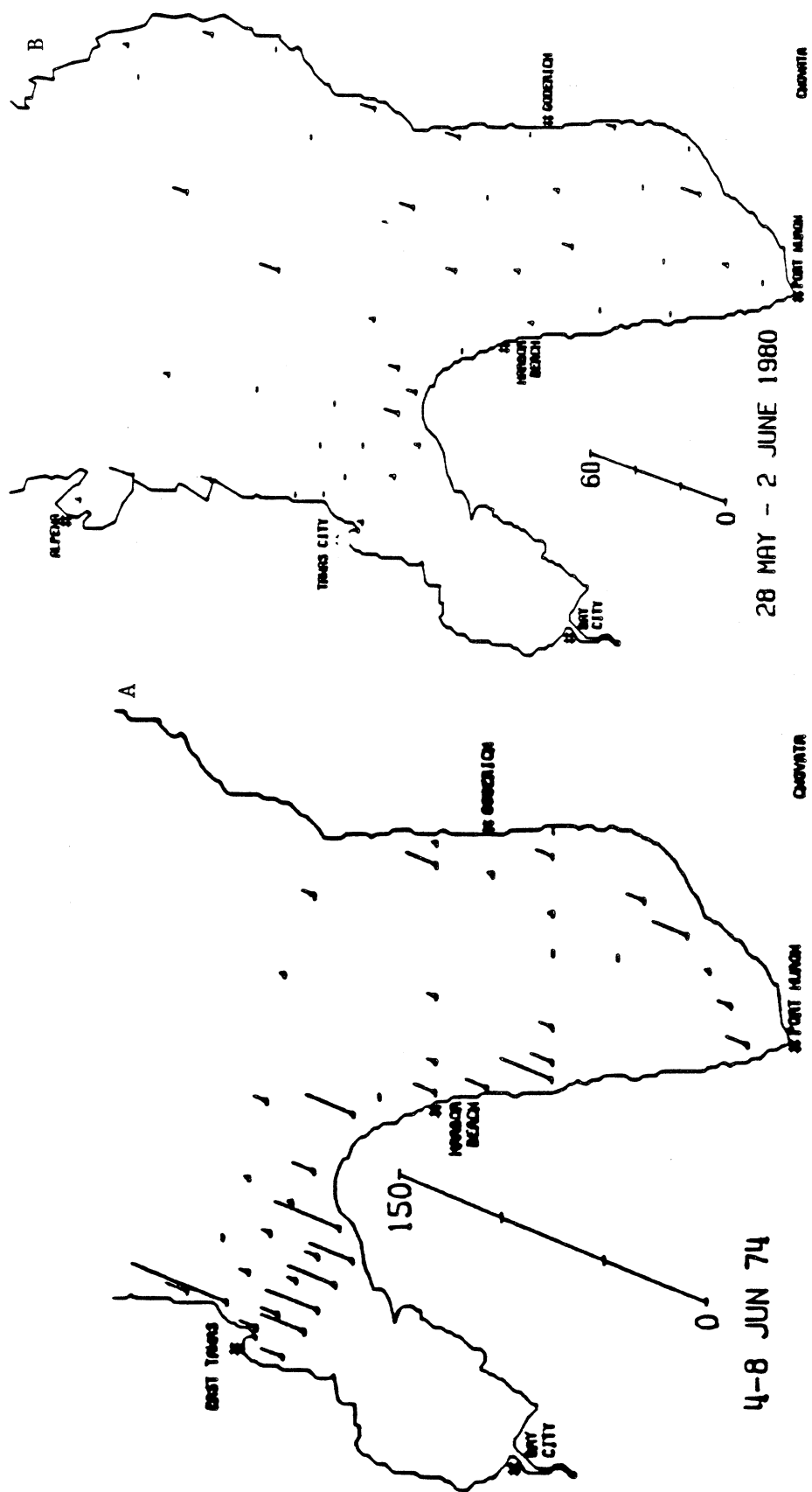


FIG. 124. Distribution and abundance (cells/mL) of *Cryptomonas ovata*, June 1974 (A) and 1980 (B).

present in all regions of the lake but exhibited an erratic distribution pattern (Fig. 124B).

Dinoflagellates were typically a minor component of algal assemblages in southern Lake Huron, occurring at less than 20 cells/mL at maximum abundance. Peridinium spp. showed lower abundances in 1980 compared to 1974. Peridinium aciculiferum, which was observed solely in outer Saginaw Bay during 1974, was not recorded in 1980. Conversely, Gymnodinium spp. were more prevalent in 1980, primarily due to increases of G. ordinatum and G. helveticum. Also a small, asymmetric dinoflagellate, Spirodinium pusillum var. minor, showed an increase in abundance and occurrence. Probably the best known dinoflagellate in the Great Lakes, Ceratium hirundinella, remained unchanged in abundance between years.

A small, undetermined flagellate, designated as flagellate sp. #15, was abundant and sometimes dominant in 1980 but was not observed in 1974. If it was present during 1974, it did not attain the substantial abundances observed in 1980. This flagellate was recorded in highest densities in the spring of 1980. During April 1980, high abundances were observed in the nearshore zone between Alpena and Tawas City with lower abundances in the Saginaw Bay interface during April (Fig. 125A). In May, its abundance was greatly reduced, especially in the U.S. nearshore zone of the central basin, but was widespread throughout the study area (Fig. 125B).

#### PHYTOPLANKTON ASSOCIATIONS IN SOUTHERN LAKE HURON, 1974 AND 1980, AS DETERMINED BY PRINCIPAL COMPONENT ANALYSIS

Principal component analysis (PCA) is a form of dimensional ordination which is utilized here to define geographic algal associations in southern

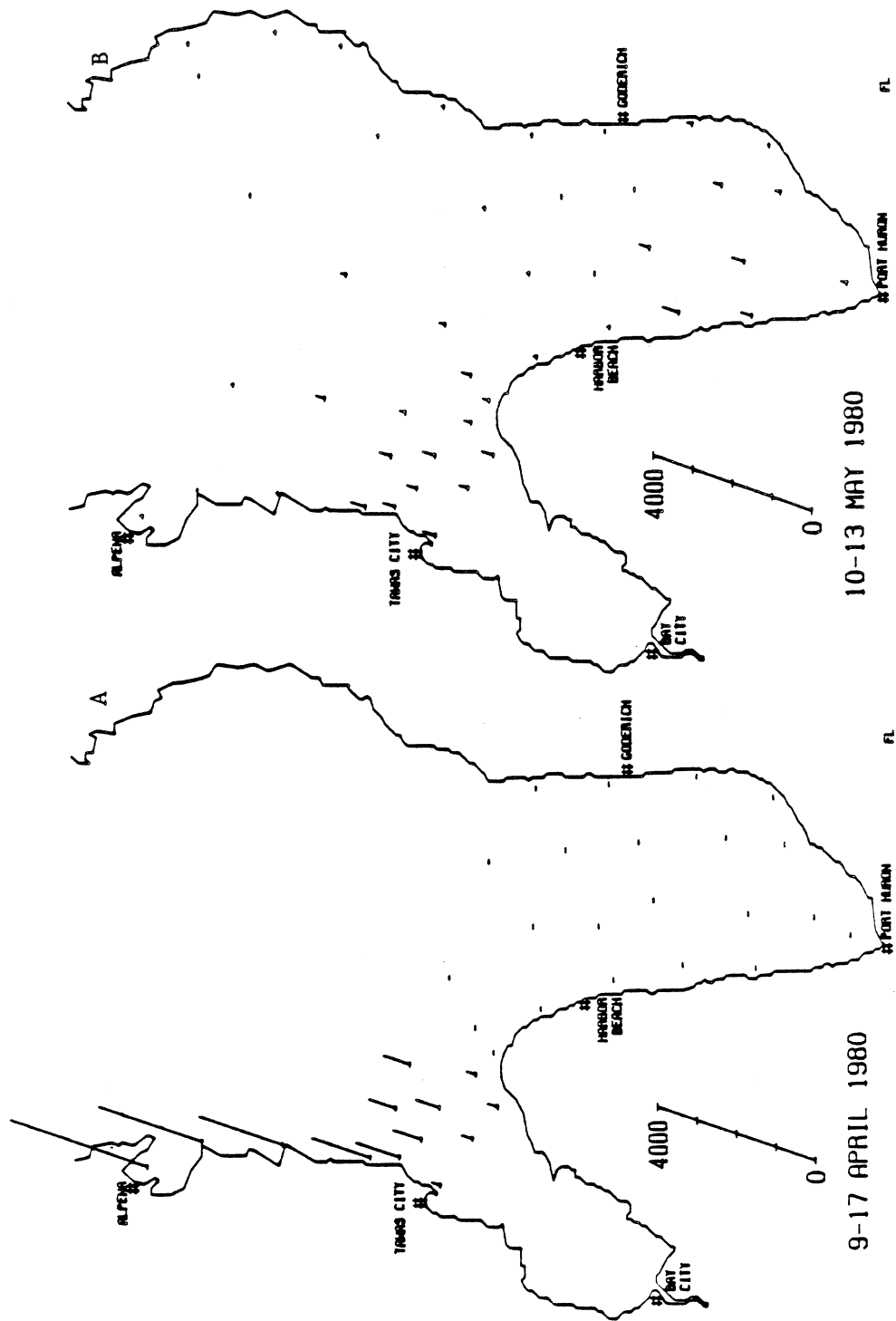


FIG. 125. Distribution and abundance (cells/mL) of flagellate sp. #15, April 1980 (A) and May 1980 (B).

Lake Huron. This multivariate technique affords a simultaneous analysis of major algal populations in regard to their distribution and abundance, delineating geographic regions which contain characteristic co-occurring populations. The regions identified are typically homogeneous water masses representative of water quality conditions. The PCA results for 1974 and 1980 are compared and contrasted.

Distributional patterns of algal species and the major algal groups depict their respective ranges and regional preferences but intrinsic assemblage relationships are neglected. Similarly, comparisons based on the IJC segmentation scheme demonstrate differences over time and within the study area but are spatially fixed and may not necessarily illustrate assemblage relationships between segments. Relationships between segments may be undetected or muted so that the extent of the relationship cannot be determined. This is particularly true when water masses are common to adjacent segments. However, the use of principal component analysis detects assemblage differences and similarities which transcend artificial boundaries and are neglected by inspecting individual distributional patterns of algal populations. A more complete account of principal component analysis procedures that have been utilized to determine Great Lakes phytoplankton associations can be found in Stoermer et al. (1976), Stoermer and Ladewski (1978), and Stoermer and Kreis (1980).

The lake regions determined by principal component analysis are presented in Figures 126 and 127 for 1974 and 1980, respectively. These maps show the major floristic and abundance associations found in southern Lake Huron for the two years. Individual cruises may also be analyzed using this method, however, summarizing regional groups over all cruises has been chosen, since

each individual cruise is a contributing component and is represented in the general summary. Mean total phytoplankton densities and abundances of the major algal divisions are presented by lake region in Tables 30 and 31 for 1974 and 1980, respectively. Individual species and assemblages characteristic of particular regions are discussed below.

During 1974, principal component analysis identified six major floristic associations composed of two strictly nearshore zones, two zones that were a mixture of nearshore and offshore stations and two predominantly offshore regions (Fig. 126). In 1980, five lake regions were defined, three nearshore zones and two offshore zones (Fig. 127). Three major conclusions can be drawn from comparing these results. First, characteristic Saginaw Bay algal assemblages were more widespread during 1974 than in 1980. Secondly, the Canadian nearshore region exerted a more profound effect in the southern basin in 1974 than during 1980. And lastly, in combining the above points, offshore algal associations had a much wider range in 1980 than in 1974, indicating that a larger expanse of the study area was unaffected by nearshore zones and Saginaw Bay.

Region A from 1974 can be directly compared to regions A<sub>1</sub> and A<sub>2</sub> from the 1980 results (Figs. 126 and 127). These regions are represented by stations in the Michigan coastal zone, north of Tawas City. Both regions are strictly nearshore and, although clustered as distinct from Saginaw Bay, they temporally contained assemblages characteristic of the Saginaw Bay water mass. These zones maintained relatively high total phytoplankton standing crops during both years (Tables 30 and 31), but a significant increase ( $p < 0.05$ ) was observed between 1974 and 1980.

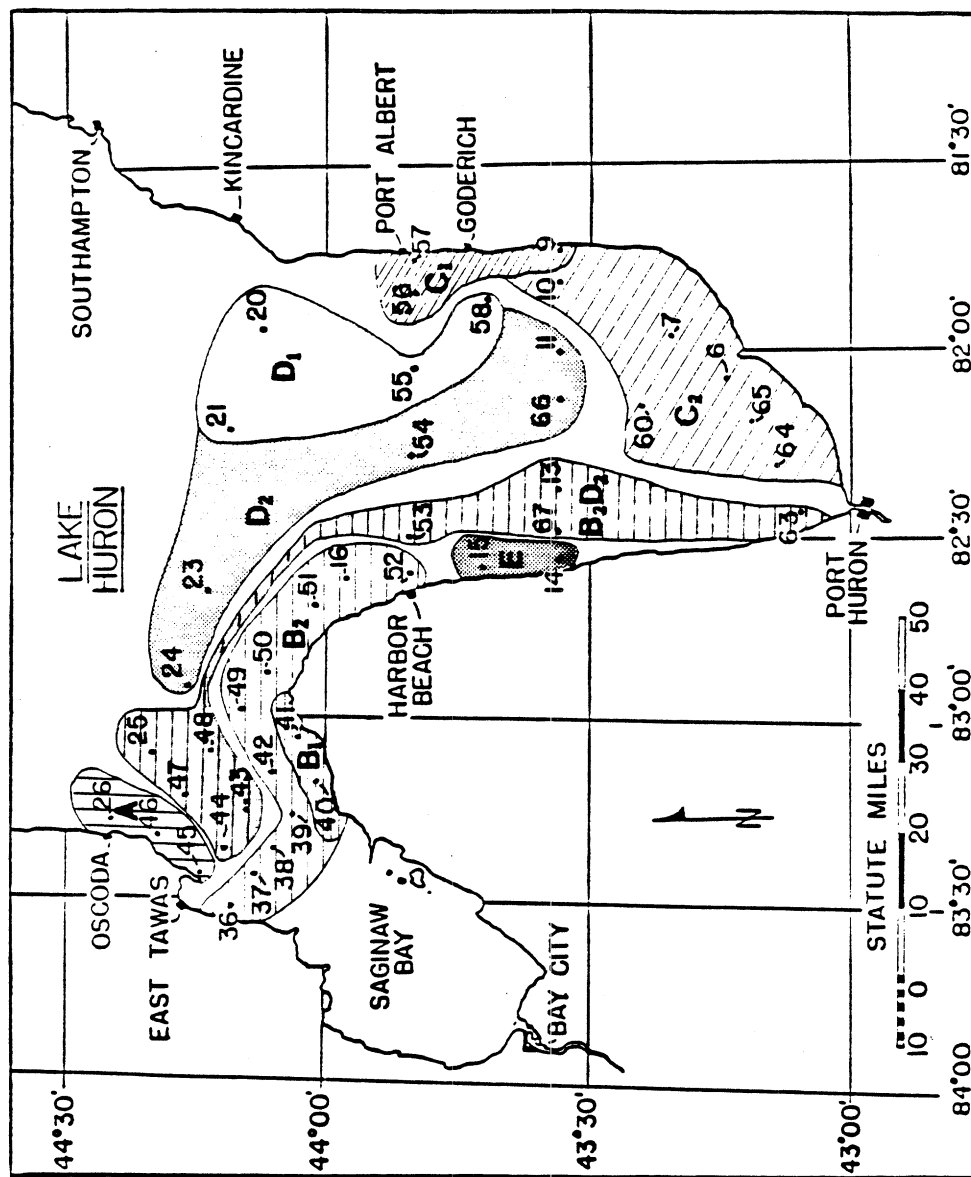


FIG. 126. Phytoplankton associations in southern Lake Huron, 1974, as determined by principal component analysis.

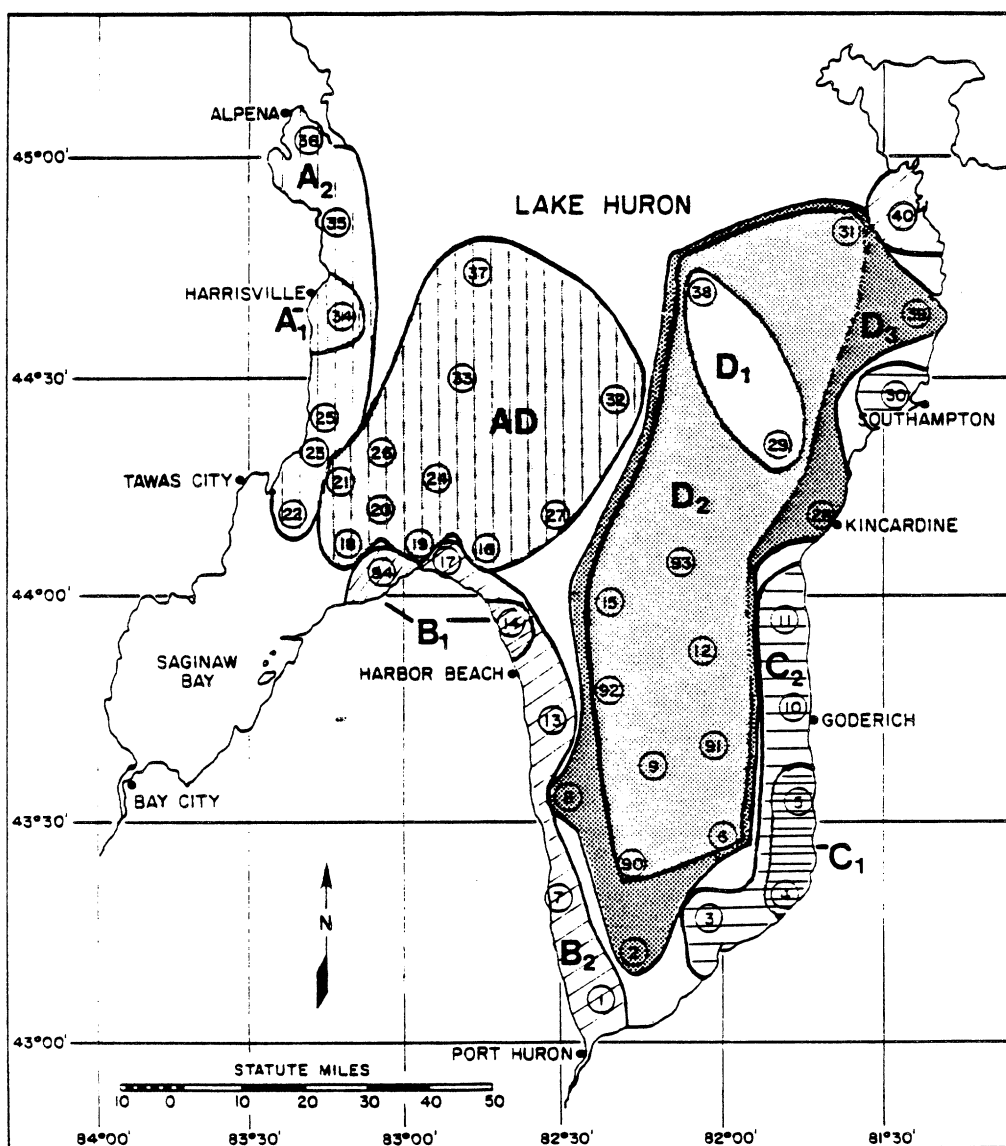


FIG. 127. Phytoplankton associations in southern Lake Huron, 1980, as determined by principal component analysis.

TABLE 30. Mean total phytoplankton cell densities (cells/mL) and abundances of the major algal groups by lake region, 1974.

REGION n	GROUP								
	TOTAL ABUNDANCE	BLUE-GREENS	GREENS	DIATOMS	CHRYSOPHYTES	CRYPTOMONADS	DINOFIAGELLATES	UNDETERMINED MICROFIAGELLATES	
A	3	1,972.3	226.9	501.2	1,028.4	139.8	16.2	1.5	58.0
B1	2	9,807.3	1,514.7	6,380.4	1,707.5	66.0	32.5	2.4	103.7
B2	10	2,952.1	617.7	1,331.1	818.1	91.8	17.5	1.6	74.0
C1	3	1,346.5	50.4	95.2	1,136.3	23.9	9.5	1.1	30.2
C2	6	1,150.2	244.0	98.3	706.1	47.3	12.6	1.2	40.8
D1	4	864.0	107.1	197.2	471.5	17.8	22.3	0.7	47.4
D2	5	1,083.4	261.8	184.8	507.7	62.2	15.4	1.3	50.3
B2D2	9	1,267.4	277.2	221.3	596.2	99.5	14.5	1.1	57.6
E	2	2,098.9	271.7	531.7	1,152.9	65.7	18.2	1.1	57.4

TABLE 31. Mean total phytoplankton cell densities (cells/mL) and abundances of the major algal groups by lake region, 1980.

		GROUP								
REGION	n	TOTAL ABUNDANCE	BLUE-GREENS	GREENS	DIATOMS	CHRYSOPHYTES	CRYPTOMONADS	DINOFIAGELLATES	UNDETERMINED MICROFIAGELLATES	
A1	1	2,731.1	535.1	95.6	1,122.6	185.0	82.4	8.7	1,000.7	
A2	5	2,846.0	599.2	116.2	1,011.4	234.2	121.82	5.4	969.5	
B1	2	3,115.4	526.2	155.8	1,551.9	290.3	151.2	8.2	431.8	
B2	5	2,035.0	362.6	108.3	920.4	189.9	128.5	5.7	319.0	
C1	2	1,828.4	293.6	118.0	828.5	177.5	154.3	8.5	248.0	
C2	4	1,496.6	237.5	79.6	521.8	232.7	128.8	5.4	286.4	
D1	2	1,030.4	227.0	26.2	251.5	135.1	159.0	2.1	229.6	
D2	9	1,421.0	359.5	83.9	406.5	165.3	166.6	5.1	232.8	
D3	4	1,550.5	302.9	83.5	549.5	202.5	115.9	4.6	291.7	
AD	11	1,817.8	515.0	99.4	447.1	204.3	148.6	4.7	398.6	

Diatoms were dominant during both years, but high abundances of undetermined microflagellates were also observed in 1980 (Tables 30 and 31). Blue-green algae increased in region A between 1974 and 1980. This region contained the highest blue-green abundances in the study area during 1980. Green algae significantly decreased ( $p < 0.05$ ) between years. Chrysophytes slightly increased but cryptomonads significantly increased ( $p < 0.05$ ) between years.

During 1974, region A was characterized by large populations of Cyclotella comensis, Gloeotila sp., Fragilaria crotonensis, Synedra filiformis, and Gomphosphaeria lacustris. In 1980, high abundances of Cyclotella comensis, flagellate sp. #15, Gomphosphaeria lacustris, Ochromonas sp. #2, and Anaystis incerta were observed. As might be suspected in a nearshore zone, large abundances of benthic and periphytic taxa belonging to the genera Achnanthes, Fragilaria, Navicula, and Nitzschia were also recorded.

During 1974 in region A, primarily diatom taxa were dominant in the spring; these included Synedra filiformis, Fragilaria crotonensis, Tabellaria fenestrata, and Rhizosolenia eriensis. These species showed reduced abundances during 1980 and species composition shifted to a flagellate dominated assemblage that included flagellate sp. #15, Ochromonas sp. #2, Rhodomonas minuta, and R. minuta var. nannoplanctica. Oscillatoria bornetii was also substantially higher in 1980.

Summer assemblages were very similar between years with Fragilaria crotonensis, Asterionella formosa, Cyclotella stelligera, and Tabellaria fenestrata all prevalent. However, increases in Cyclotella comensis, Dinobryon divergens, and undetermined microflagellates were observed in 1980.

Fall assemblages for both years in region A were characterized by Cyclotella comensis, Gomphosphaeria lacustris, Anacystis incerta, and Fragilaria crotonensis. Typically, increased abundances of these populations were recorded in 1980, with higher densities of Ochromonas sp. #2 and Rhodomonas minuta var. nannoplanctica also observed.

Throughout all seasons, temporal effects of Saginaw Bay could be detected in the assemblages of region A. Populations of Aphanizomenon flos-aquae, Fragilaria capucina, Gloeotila sp., and Diatoma tenue var. elongatum were observed. However, when present, much smaller abundances of these populations were recorded in 1980.

Regions B<sub>1</sub> and B<sub>2</sub> during 1974 included both nearshore and marginally offshore stations in outer Saginaw Bay and southward to Harbor Beach (Fig. 126). During 1980, zones B<sub>1</sub> and B<sub>2</sub> were composed of nearshore stations from the southeast corner of Saginaw Bay southward to Port Huron (Fig. 127). In both cases, region B<sub>1</sub> contained the most eutrophic species association observed in southern Lake Huron and was situated in the main exiting flow of the Saginaw Bay water mass. Zones B<sub>2</sub> for both years showed lower densities than zones B<sub>1</sub>, although strong species association similarities existed between these zones. Also region B<sub>2</sub>D<sub>2</sub> showed temporal effects of the Saginaw Bay water mass with characteristic Saginaw Bay assemblages. However, this region did not have an analog in the 1980 results and cannot be adequately compared.

Highest mean total standing crops in southern Lake Huron were recorded for region B<sub>1</sub> and B<sub>2</sub> during each respective year (Tables 30 and 31). Similarly, highest abundances of most of the major physiological groups were

recorded in these zones. During 1974, green algae dominated regions B<sub>1</sub> and B<sub>2</sub>. Green algae remained comparatively abundant in 1980 but were significantly reduced ( $p < 0.05$ ) from 1974 abundances. Diatoms dominated in regions B<sub>1</sub> and B<sub>2</sub> during 1980 and showed slight decreases as compared to 1974. Blue-green abundance was also much higher in 1974, although during 1980 blue-greens were still relatively abundant. Chrysophytes, cryptomonads, dinoflagellates, and undetermined microflagellates significantly increased ( $p < 0.05$ ) in 1980 compared to 1974.

During 1974, regions B<sub>1</sub> and B<sub>2</sub> were generally characterized by high abundances of Gloeotila sp., Fragilaria capucina, Aphanizomenon flos-aquae, Anacystis incerta, Fragilaria crotonensis, Cyclotella comensis, Gomphosphaeria lacustris, and Anabaena flos-aquae. In 1980, several of these taxa were severely reduced and not abundant in these regions but some of the same taxa were prevalent, for example, Cyclotella comensis, Fragilaria crotonensis, Anacystis incerta, and Gomphosphaeria lacustris. Populations with increased abundances between years were Ochromonas sp. #2, Anacystis thermalis, flagellate sp. #15, Rhodomonas minuta var. nannoplanctica, and Schizothrix calcicola.

During the spring of 1974, Gloeotila sp. was dominant, with high abundances of Fragilaria capucina. Also prevalent in regions B<sub>1</sub> and B<sub>2</sub> were Diatoma tenue var. elongatum, Stephanodiscus binderanus, Tabellaria fenestrata, Oscillatoria retzii, and Fragilaria crotonensis. Total abundances were drastically reduced in regions B<sub>1</sub> and B<sub>2</sub> during the spring of 1980 and Fragilaria capucina was the dominant. Other taxa in high abundances were predominantly flagellate populations such as Ochromonas sp. #2, flagellate

sp. #15, Chroomonas spp., Rhodomonas minuta var. nannoplanctica, and Synedra filiformis.

During the summer, greatly reduced abundances were observed constituting the summer minimum. However, Gloeotila sp. again dominated in 1974, with Dinobryon divergens, Chroococcus dispersus fo. minor, Coelastrum microporum, and undetermined flagellates showing relatively high abundances. During the summer of 1980, Cyclotella comensis was dominant, Gloeocystis planctonica subdominant, and Fragilaria crotonensis and Dinobryon divergens common.

During the fall of 1974, Gloeotila sp. was again dominant in these zones and Aphanizomenon flos-aquae was subdominant. Fragilaria capucina, Anacystis cyanea, Cyclotella comensis, and Anacystis incerta showed relatively high abundances in this fall assemblage. During 1980, fall assemblages were dominated by Fragilaria capucina. Other predominate taxa were Cyclotella comensis, Gomphosphaeria lacustris, and undetermined microflagellates.

Lake associations designated C<sub>1</sub> and C<sub>2</sub> for 1974 and 1980 are predominantly nearshore zones in the Canadian sector of the southern basin (Figs. 126 and 127). The primary regions, C<sub>1</sub> of both years, geographically overlap south of Goderich but extended farther north in 1974 and farther southward in 1980. Also during 1974, region C<sub>2</sub> encompassed some offshore stations. During 1980, station 30, near Southampton, was also included in zone C<sub>2</sub>.

Total phytoplankton abundance modestly increased in region C between 1974 and 1980 (Tables 30 and 31). Diatoms were the most abundant algal group during both years but significantly decreased ( $p < 0.05$ ) in 1980. Blue-green algae significantly increased ( $p < 0.05$ ) between years with green algae showing

somewhat lower densities in 1980. All flagellate groups significantly increased ( $p < 0.05$ ) between 1974 and 1980.

During 1974, Cyclotella comensis, Melosira islandica, Cyclotella stelligera, and Fragilaria crotonensis showed highest abundances in region C. In 1980, Cyclotella comensis, Fragilaria crotonensis, Gomphosphaeria lacustris, and Rhodomonas minuta var. nannoplanctica characterized the assemblages.

During the spring of 1974, Melosira islandica dominated region C., Fragilaria capucina, F. intermedia var. fallax, Stephanodiscus minutus, and S. hantzschii were also abundant. In 1980, spring assemblages were distinctly different. Fragilaria crotonensis, undetermined microflagellates, Rhodomonas minuta var. nannoplanctica, Coccomyxa minor, and Oscillatoria bornetii accounted for large portions of the assemblages.

Summer assemblages during 1974 were dominated by Cyclotella stelligera. Comparatively high abundances of undetermined microflagellates, Cyclotella sp. #5, Cyclotella ocellata, and Tabellaria flocculosa var. linearis were observed. In the summer of 1980, Cyclotella comensis dominated and undetermined microflagellates were subdominant. Cyclotella stelligera and Rhodomonas minuta var. nannoplanctica were common.

Fall assemblages in region C were dominated by Cyclotella comensis in 1974. Anacystis incerta, Asterionella formosa, and Chrysosphaerella longispina were prevalent. Similar dominants were observed in 1980, with Anacystis incerta and Cyclotella comensis co-dominant. Undetermined microflagellates, Fragilaria intermedia var. fallax, Schizothrix calcicola, and Oscillatoria bornetii had comparatively high abundances in these assemblages during 1980.

Regions  $D_1$  and  $D_2$  in 1974 and regions  $D_1$ ,  $D_2$ , and  $D_3$  in 1980 were the primary offshore zones in the study area (Figs. 126 and 127). Several geographic differences exist between these regions. Zone  $D_2$  during 1974 extends farther to the west than any station in zone D during 1980. Region AD occupied this geographic area in 1980 and is a mixture of regions A and D. Region AD shows some similarities to region  $D_2$  in 1974 because of common offshore species; however, region AD was distinctly influenced by region A in 1980 and cannot be compared to region D in 1974. Similarly, AD cannot be compared to region  $B_2D_2$  in 1974 because of the temporal influence exerted by Saginaw Bay on  $B_2D_2$  which is lacking in zone AD. Another difference between years is that region  $D_3$  includes several stations in nearshore areas, whereas zone D in 1974 is strictly offshore. The last obvious difference is that region D in 1980 is larger and extends deeper into the southern basin than during 1974.

Regions  $D_1$  and  $D_2$  in 1974 and regions  $D_1$ ,  $D_2$ , and  $D_3$  in 1980 exhibited the lowest standing crops observed in southern Lake Huron (Tables 30 and 31) and were typically dominated by offshore species. In these regions,  $D_1$  showed the lowest phytoplankton standing crops, with consecutively higher abundances in zones  $D_2$  and  $D_3$ . The assemblages observed in these regions were the most representative of oligotrophic conditions in the study area.

Lowest abundances of total phytoplankton as well as lowest abundances of the major algal groups were typically recorded for these zones. Diatoms were the most abundant group in these regions (Tables 30 and 31) but were significantly reduced ( $p < 0.05$ ) in 1980. Blue-greens were generally common in these regions and green algae showed significantly lower ( $p < 0.05$ ) abundances

in 1980. All flagellate groups were significantly higher ( $p < 0.05$ ) in the offshore waters during 1980.

During 1974, zone D contained characteristic populations of Gloeocystis planctonica, Cyclotella stelligera, Anacystis incerta, Cyclotella comensis, Rhizosolenia eriensis, Synedra filiformis, and Cyclotella ocellata. In 1980, region D assemblages were represented by populations of Gomphosphaeria lacustris, Rhodomonas minuta var. nannoplanctica, Ochromonas sp. #2, Cyclotella comensis, Asterionella formosa, and Rhodomonas minuta. These assemblages differed considerably between years.

Spring assemblages in region D during 1974 consisted of populations of Tabellaria fenestrata, Synedra filiformis, Asterionella formosa, Cyclotella stelligera, and Rhizosolenia eriensis. During the spring of 1980, flagellate species such as Ochromonas sp. #2, Rhodomonas minuta var. nannoplanctica, and undetermined flagellates were prevalent with distinctly lower abundances of diatoms. Oscillatoria bornetii was also relatively abundant in this region during the spring and showed increases over densities recorded in 1974.

In 1974, Fragilaria crotonensis and Cyclotella stelligera were co-dominant during the summer minimum in region D. Also present in the assemblages were relatively high abundances of Cyclotella ocellata, undetermined microflagellates, and Cyclotella sp. #5. In 1980, Cyclotella comensis, undetermined flagellates, and Gloeocystis planctonica comprised large portions of the assemblages.

Fall assemblages in 1974 were represented by Cyclotella comensis, Anacystis thermalis, undetermined flagellates, and Asterionella formosa in region D. During 1980, Gomphosphaeria lacustris, undetermined flagellates,

Ochromonas sp. #2, Chrysosphaerella longispina, and Cyclotella comensis were prevalent in the assemblages.

Lake region E in 1974 did not have an analog region in 1980 (Figs. 126 and 127). Geographically it was similar to the location of station 13 in 1980, which was located in zone B<sub>2</sub>. However, the stations in region E during 1974 were located farther shoreward than station 13, and nearshore influences may account for this region in 1974. Region E did show temporal effects of the Saginaw Bay water mass in 1974 but assemblages were dissimilar enough to constitute another distinct region. This zone was characterized by large abundances of Gloeotila sp., Cyclotella comensis, Fragilaria crotonensis, Anacystis incerta, and Tabellaria fenestrata.

Table 32 presents a summary of abundance differences observed in populations, total phytoplankton, and the major algal groups between 1974 and 1980 for each lake association. The major taxa characteristic of each zone were previously discussed and additional species are presented (Table 32). Analysis of variance tests were utilized for matched stations within each region between years to determine abundance differences. As in the species discussion, large population variances influenced analysis of variance tests and significant differences were not always obtained even though absolute differences were considerable. Stations in these analyses may have a locational analog in regions of similar phytoplankton associations to be included.

TABLE 32. Summary of abundance differences observed in algal populations, total phytoplankton, and the major algal groups, between 1974 and 1980, for each PCA association region.

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Region A (1974) vs. Regions A<sub>1</sub> and A<sub>2</sub> (1980)

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<u>Decreased</u>	<u>Increased</u>
<u>Asterionella formosa*</u>	<u>Anacystis incerta</u>
<u>Aphanizomenon flos-aquae</u>	<u>Anacystis thermalis</u>
<u>Cyclotella comta</u>	<u>Cyclotella comensis*</u>
<u>Cyclotella michiganiana*</u>	<u>Dinobryon divergens*</u>
<u>Cyclotella ocellata*</u>	<u>Flagellate sp.#15*</u>
<u>Cyclotella stelligera</u>	<u>Fragilaria capucina</u>
<u>Fragilaria crotonensis</u>	<u>Fragilaria pinnata</u>
<u>Gloeotila sp.*</u>	<u>Gomphosphaeria lacustris</u>
<u>Melosira granulata</u>	<u>Ochromonas sp.#2*</u>
<u>Mougeotia sp.#1*</u>	<u>Oscillatoria bornetii*</u>
<u>Nitzschia acicularis*</u>	<u>Rhodomonas minuta*</u>
<u>Rhizosolenia eriensis</u>	<u>Rhodomonas minuta var. nannoplanctica*</u>
<u>Stephanodiscus binderanus</u>	<u>Schizothrix calcicola</u>
<u>Synedra filiformis*</u>	Total phytoplankton abundance*
<u>Tabellaria fenestrata</u>	Blue-greens
<u>Green algae*</u>	Diatoms
	Cryptomonads*
	Chrysophytes
	Dinoflagellates

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Regions B<sub>1</sub> and B<sub>2</sub> (1974) vs. Regions B<sub>1</sub> and B<sub>2</sub> (1980)

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<u>Decreased</u>	<u>Increased</u>
<u>Anabaena flos-aquae*</u>	<u>Ankistrodesmus sp.#3*</u>
<u>Asterionella formosa*</u>	<u>Anacystis thermalis*</u>
<u>Aphanizomenon flos-aquae</u>	<u>Cyclotella comensis*</u>
<u>Cryptomonas ovata</u>	<u>Flagellate sp.#15*</u>
<u>Cyclotella comta*</u>	<u>Fragilaria pinnata*</u>
<u>Cyclotella michiganiana</u>	<u>Ochromonas sp.#2*</u>
<u>Diatoma tenue var. elongatum</u>	<u>Oscillatoria bornetii*</u>
<u>Fragilaria crotonensis*</u>	<u>Rhodomonas minuta*</u>
<u>Gloeotila sp.*</u>	<u>Rhodomonas minuta var. nannoplanctica*</u>
<u>Melosira granulata*</u>	<u>Schizothrix calcicola</u>
<u>Mougeotia sp.#1*</u>	Total phytoplankton abundance
<u>Stephanodiscus binderanus</u>	Diatoms
Blue-greens	Chrysophytes*
Green algae*	Cryptomonads*
	Dinoflagellates*

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\*statistically significant (p<0.05)

(continued)

TABLE 32. (continued).

Regions C<sub>1</sub> and C<sub>2</sub> (1974) vs. Regions C<sub>1</sub> and C<sub>2</sub> (1980)

<u>Decreased</u>	<u>Increased</u>
<u>Cyclotella michiganiana</u>	<u>Ankistrodesmus</u> sp.#3
<u>Cyclotella</u> sp.#5	<u>Anacystis incerta</u>
<u>Cyclotella stelligera</u> *	<u>Anacystis thermalis</u>
<u>Fragilaria capucina</u>	<u>Dinobryon divergens</u>
<u>Melosira granulata</u>	<u>Fragilaria crotonensis</u>
<u>Melosira islandica</u>	<u>Ochromonas</u> sp.#2
<u>Nitzschia dissipata</u> *	<u>Oscillatoria bornetii</u> *
<u>Stephanodiscus hantzschii</u>	<u>Rhodomonas minuta</u> *
<u>Stephanodiscus minutus</u>	<u>Rhodomonas minuta</u> var. <u>nannoplanctica</u> *
<u>Synedra filiformis</u>	<u>Rhizosolenia eriensis</u>
Green algae	<u>Schizothrix calcicola</u> *
Diatoms*	Total phytoplankton abundance
	Blue-greens*
	Chrysophytes*
	Cryptomonads*
	Dinoflagellates*

Regions D<sub>1</sub> and D<sub>2</sub> (1974) vs. Regions D<sub>1</sub>, D<sub>2</sub> and D<sub>3</sub> (1980)

<u>Decreased</u>	<u>Increased</u>
<u>Aphanizomenon flos-aquae</u> *	<u>Asterionella formosa</u>
<u>Cyclotella comta</u>	<u>Anacystis thermalis</u>
<u>Cyclotella michiganiana</u> *	<u>Cyclotella pseudostelligera</u> *
<u>Cyclotella ocellata</u> *	<u>Dinobryon divergens</u> *
<u>Cyclotella operculata</u> *	<u>Flagellate</u> sp.#15*
<u>Cyclotella</u> sp.#5*	<u>Gomphosphaeria lacustris</u>
<u>Cyclotella stelligera</u> *	<u>Melosira islandica</u> *
<u>Gloeocystis planctonica</u> *	<u>Ochromonas</u> sp.#2*
<u>Rhizosolenia eriensis</u>	<u>Oscillatoria bornetii</u> *
<u>Stephanodiscus alpinus</u> *	<u>Rhodomonas minuta</u> *
<u>Synedra filiformis</u> *	<u>Rhodomonas minuta</u> var. <u>nannoplanctica</u> *
<u>Tabellaria fenestrata</u>	<u>Stephanodiscus minutus</u> *
Green algae*	<u>Schizothrix calcicola</u> *
Diatoms*	Total phytoplankton abundance*
	Blue-greens
	Chrysophytes*
	Cryptomonads*
	Dinoflagellates*

\*statistically significant (p&lt;0.05)

## DISCUSSION

Analysis of southern Lake Huron phytoplankton assemblages revealed that five major floristic regions were present in the study area during 1980. These regions appear to correspond to nutrient loading gradients and support algal abundances and floristic components indicative of their degree of enrichment. Phytoplankton association regions showed a distinct nearshore-offshore differentiation where nearshore areas and outer Saginaw Bay supported substantially larger algal abundances, compared to offshore zones.

Outer Saginaw Bay exhibited the highest algal standing crops in the study area and maintained populations that are characteristic of eutrophy. Our results indicate that Saginaw Bay is the most severely impacted region in southern Lake Huron, apparently in response to cultural eutrophication and anthropogenic loadings. As early as 1965, Saginaw Bay was recognized to contain substantially higher phytoplankton standing crops and distinctively more eutrophic populations than were observed for the remainder of the lake (U.S. Dept. Int. 1965a and b). This observation has also been subsequently reported by Schelske *et al.* (1974a), Lowe (1976), and Stoermer and Kreis (1980). Freedman (1974) has previously discussed the long history of high ambient nutrient concentrations, taste and odor problems, and conservative ion loadings in Saginaw Bay. Saginaw Bay supports algal populations which are indicative of only the most impacted areas of the Great Lakes such as in Green Bay and the western end of Lake Erie. Eutrophic species observed in Saginaw Bay during 1980 were Anabaena flos-aquae, Anacystis cyanea, Actinocyclus normanii fo. subsalsa, Fragilaria capucina, Diatoma tenue var. elongatum, Melosira granulata, and Stephanodiscus binderanus. The nearshore area south

of Saginaw Bay appears to be temporally influenced by the discharge of Saginaw Bay populations and generally supports comparatively high algal concentrations. Typically, the Saginaw Bay water mass exits over the thumb area, transporting eutrophic algal populations to the main lake (Stoermer and Kreis 1980). Localized shoreline inputs may restimulate senescent populations transported from Saginaw Bay, but no particular area was suspected of substantial nutrient loadings.

The nearshore zone on the Michigan coastline of the central basin also exhibited relatively high phytoplankton cell densities and contained some eutrophic species. Although cell concentrations were not as great as observed in Saginaw Bay, similar eutrophic populations such as Anabaena flos-aquae and Diatoma tenue var. elongatum were recorded. However, a more extensive population analysis in Thunder Bay by Ladewski et al. (1982) showed the presence of other eutrophic taxa such as Melosira granulata, Stephanodiscus binderanus, Cyclotella meneghiniana, and Fragilaria capucina.

Thunder Bay is a fairly shallow embayment which receives the discharge of the Thunder Bay River. Several industries are located on the river and bay and have been cited as the cause for observed water quality problems (Burton 1981). In 1975 and 1976 obnoxious, gelatinous blooms of Cyclotella comensis, generally an offshore, solitary plankton diatom, interfered with fishing activities (Mich. Water Res. Comm. 1976). Although local problems have been cited in the inner Thunder Bay region, effects of the bay discharge and apparent shoreline inputs south of the bay have had a greater effect on offshore phytoplankton assemblages than previously realized. The presence of high algal standing crops which contain eutrophic species indicates that this

region should be more closely monitored in the future for the detection of further water quality degradation.

The nearshore zones on the Canadian portion of the study area do not exhibit the high standing crops as recorded for their Michigan nearshore counterparts. Typically, species observed in these areas show a wide range of tolerance or may be observed in the offshore waters of the southern or central basins. Of the three major nearshore regions investigated, this region appeared to be the least modified by anthropogenic input.

The offshore waters of southern Lake Huron show low phytoplankton standing stocks and a species composition that is characteristic of oligotrophic or meso-oligotrophic conditions. Although the offshore waters of the southern basin appear to show long-term effects of the influence of nutrient loadings from Saginaw Bay and nearshore localities, their affinities to the offshore zone of the central basin demonstrate the high water quality present in this area. The association of the offshore waters of the western central basin more clearly demonstrated the effects of the northern nearshore area and possibly Saginaw Bay on the open lake. The offshore waters of the eastern central basin showed the lowest standing crops and populations characteristic of oligotrophy, representing the best water quality observed in the study area.

Comparative analyses of phytoplankton distribution, abundance, and species composition observed in 1980 versus those in 1974 indicate several major points. First, lakewide and regional changes were observed in total phytoplankton standing crops and the major algal groups between years. Typically, when regional differences were observed, changes in Saginaw Bay ran contrary to those in the remainder of the study area. Qualitative and

quantitative improvements were observed in outer Saginaw Bay during 1980, compared to 1974. Reduced total cell densities and the absence or reduction of species characteristic of eutrophic conditions in outer Saginaw Bay were apparently due to nutrient control measures instituted during the time period (Bierman et al. 1984). Also, the influence of Saginaw Bay on the southern basin was not as extensive and pervasive during 1980.

The offshore waters of the central and southern basins of Lake Huron exhibited increased cell densities and slightly degrading water quality between 1974 and 1980. Phytoflagellate populations increased, apparently at the expense of certain diatom species. However, the offshore region in the southern basin was considerably expanded in 1980 due to the reduced influence of Saginaw Bay and the Canadian nearshore zone in the southern basin. The offshore waters of the southern basin contain species characteristic of meso-oligotrophic conditions and high water quality.

The distribution and abundance of total phytoplankton and the major algal groups in Lake Huron are dominated by the high standing crops in outer Saginaw Bay. This condition was more evident in 1974, compared to 1980. Total cell densities were 14% lower in outer Saginaw Bay in 1980, and a 10% decrease in chlorophyll a concentrations was also recorded (Kreis 1984). The greatest density change was observed in the late spring with a small, yet obvious decrease during the fall. The most dramatic reductions in cell densities were observed for blue-green and green algal populations. Diatom abundances were comparatively higher during 1980. Most importantly, certain blue-green species such as Aphanizomenon flos-aquae, Anabaena subcylindrica, and Oscillatoria retzii, which were abundant and sometimes dominant in 1974, were absent from the flora of southern Lake Huron during 1980. Other blue-green

eutrophication tolerant species such as Anabaena flos-aquae, Anacystis cyanea Mougeotia sp. #1, Gloeotila sp., Fragilaria capucina, Stephanodiscus binderanus, Cyclotella meneghiniana, and Actinocyclus normanii fo. subsalsa were considerably reduced in 1980.

The reduction in total cell densities and absence or reduction of characteristically eutrophic species in outer Saginaw Bay during 1980 is in apparent response to the nutrient loading abatement program instituted in the Saginaw River watershed between 1974 and 1980. Bierman et al. (1984) have discussed phosphorus loading reductions from the Saginaw River in relation to reductions in chlorophyll a concentrations in inner Saginaw Bay. The nutrient abatement program has primarily focused on phosphorus removal through upgraded sewage treatment facilities and the phosphorus detergent ban. Between 1974 and 1980, total phosphorus and ortho-phosphorus decreased by 36% and 81%, respectively, in outer Saginaw Bay (Kreis 1984).

Phytoplankton abundances increased in all other regions of the study area. Algal standing crop was 33% higher in the lower central basin between years. Total phosphorus increased by 37% and chlorophyll a exhibited a 67% increase between years (Kreis 1984). Algal abundances in the U.S. sector of the southern basin increased by 33% between years and total-P and chlorophyll a were 1% and 9% higher, respectively. Although a 19% increase in algal abundance was observed in the Canadian sector of the southern basin, total-P and chlorophyll a decreased by 20% and 2%, respectively. Even though similar qualitative changes occurred in all three regions, the most pronounced differences were recorded for the Canadian portion of the southern basin.

Typically, phytoflagellate populations significantly increased in these regions between years; particularly during the spring months. Diatom

populations showed significant reductions. Flagellate taxa such as Dinobryon divergens, Ochromonas sp. #2, Rhodomonas minuta, and R. minuta var. nannoplanctica significantly increased. Also, blue-green taxa such as Anacystis thermalis, Gomphosphaeria lacustris, Oscillatoria bornetii, and Schizothrix calcicola showed sizeable and usually significantly higher abundances during the spring months in these regions.

Several populations in the offshore zones, primarily diatoms, were reduced in 1980. Representatives of the oligotrophic flora, particularly in the genus Cyclotella, showed significant decreases. Cyclotella comta, C. michiganiana, C. ocellata, C. operculata, and C. stelligera declined significantly between years. Other diatom taxa such as Fragilaria intermedia var. fallax, Stephanodiscus transilvanicus, Synedra ostenfeldii, S. ulna var. chaseana, and Tabellaria fenestrata were not as abundant in 1980, compared to 1974.

Although the offshore waters in the study area continued to represent high water quality in 1980, the qualitative changes observed may indicate slightly degrading conditions. These offshore zones show modest signs of eutrophication and appear to have advanced into the early stages of the eutrophication sequence as postulated by Stoermer (1978). The most prominent features are the distinct spring and fall maxima, declines in the indigenous flora, and the occurrence of newly introduced taxa.

The distribution of algal assemblages and the results of principal component analysis indicated that the effects of Saginaw Bay on the open lake diminished considerably in 1980. Similarly, the Canadian nearshore zone was not as influential on the southern basin during 1980, compared to 1974. The reduced influence of these two zones resulted in a greater expanse of the

southern basin to be associated with conditions more closely aligned with meso-oligotrophic conditions.

During 1974, algal distributions suggested that certain Saginaw Bay populations were passively dispersed throughout the southern basin. Some populations appeared to persist in the water column longer than others, but many were capable of surviving transport for considerable distances. The results of principal component analysis and the inspection of algal distributions indicate that eutrophic populations generated in Saginaw Bay have been primarily confined to Saginaw Bay in 1980.

The ramifications of algal transport are considerable. Some algal populations, including those of Saginaw Bay, have been shown to sorb heavy metals and organic contaminants (Sicko-Goad and Stoermer 1979, Stoermer et al. 1980, Lederman and Rhee 1982, Bistricki and Munawar 1982). When sorbed by transported algal populations, heavy metals and organic compounds may also be transported for a substantial distance, increasing their effective range farther than suspected. Thomas (1973) and Frank et al. (1979) have observed relatively high concentrations of heavy metals and organic compounds in the depositional basins of southern Lake Huron. Transported algal assemblages may be responsible for, at this juncture, an unknown portion of the allochthonous materials detected.

Particulate nutrients bound in phytoplankton biomass may also be relocated from Saginaw Bay into the open lake. Large amounts of nutrients are sequestered by Saginaw Bay algal assemblages, which would be reuseable by open lake assemblages after death and decomposition. This additional nutrient burden may be responsible for the establishment of new algal populations that would compete with the oligotrophic flora, adding a new dimension to algal

competition in the offshore zone. The possibility of nutrient supply to the offshore waters of southern Lake Huron has been implied by Thomas et al. (1973), where relatively high organic carbon concentrations have been detected in the depositional basins of Lake Huron.

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## APPENDICES

# Appendix I. Chronology of Lake Huron Algal Research.

Date	Author	Divisional Group	Site
1842	Bailey, J.W. (a)	D	Mackinaw Is.-Lake Huron
1842	Bailey, J.W. (b)	D	Mackinaw Is.-Lake Huron
1845	Ehrenberg, C.G.	D	Mackinaw Is.-Lake Huron
1847	Bailey, J.W.	G	Lake Huron
1849	Kützing, F.T.	D	Mackinaw Is.-Lake Huron
1872	Briggs, S.A.	D	Mackinaw Is.-Lake Huron
1911	Baker, H.B. <u>In: Ruthven, A.G.</u>	G	Saginaw Bay
1911	Coons, G.H. <u>In: Ruthven, A.G.</u>	G	Saginaw Bay
1911	Klugh, A.B.	G	Georgian Bay
1912	Klugh, A.B.	G	Georgian Bay
1913	Klugh, A.B.	G,B-G	Georgian Bay
1913	Klugh, A.B.	G,B-G	Georgian Bay
1915	MacClement, W.T.	D,G,B-G	Georgian Bay
1915	Boyer, C.S. <u>In: MacClement, W.T.</u>	D	Go Home Bay-Georgian Bay
1915	Klugh, A.B. <u>In: MacClement, W.T.</u>	G,B-G	Georgian Bay
1921	Bailey, L.W. and A.H. Mackay	D	Parry Sound-Georgian Bay
1924	Bailey, L.W.	D	Georgian Bay
1927	Boyer, C.S.	D	Mackinaw Is.-Lake Huron
1928	Collins, F.S.	G	Georgian Bay
1961	Schlichting, H., Jr.	D,G,B-G	Port Sanilac, Mi.-Lake Huron
1961	U.S. Public Health Service	D,G,B-G	Port Huron
1962	Fenwick, M.	D,G	Lake Huron
1962	U.S. Public Health Service	D,G,B-G	Port Huron
1962	Williams, L.G.	D	Port Huron
1962	Williams, L.G. and Scott, C.	D	Port Huron
1964	Neil, J.H. and Owen, G.E.	G	Lake Huron
1964	U.S. Public Health Service	D,G,B-G	Port Huron
1964	Williams, L.G.	D	Port Huron
1965	Beeton, A.M.	D	Lake Huron
1965	U.S. Public Health Service	D,G,B-G	Port Huron
1965	U.S. Department of the Interior (a)	D,G,Ch,B-G	Lake Huron
1965	U.S. Department of the Interior (b)	D,G,Ch,B-G	Saginaw Bay
1966	Davis, C.C.	D,G	Lake Huron
1966	Patrick, R. and C.W. Reimer	D	Mackinaw Is.-Lake Huron
1967	Bellis, V.J. and D.A. McLarty	G	Port Franks, Ont.-Lake Huron
1967	Fetteroff, C. and J. Robinson	G	Lake Huron
1967	Fetteroff, C. <u>et al.</u>	D	Thunder Bay-Lake Huron
1967	Michigan Water Res. Commission	G	Lake Huron
1968	Fenwick, M.	D,G	Lake Huron
1968	Stoermer, E.F. and J.J. Yang	D	Lake Huron
1969	Herbst, R.P.	G	Lake Huron
1969	Michalski, M.F.P. <u>In: Anderson, D.V.</u>	D,C,Ch,Cr,B-G,E,Dn,X	Lake Huron
1969	Parkos, W.G. <u>et al.</u>	D,G,Ch,B-G,Dn	Lake Huron
1970	Beeton, A.M. <u>In: Swain, W.R. et al.</u>	D,G,Ch,B-G,Dn	Lake Huron
1970	Robinson, J.	D,G,Ch,B-G	Lake Huron
1971	Veal, D.M. and M.F.P. Michalski	D,G,Ch,Cr,B-G	Georgian Bay
1972	Berst, A.H. and G.R. Sprangler	D	Lake Huron
1972	Williams, L.G.	D	Port Huron
1973	Hohn, M.H. <u>In: Batchelder, T.L.</u>	D,G,Ch,B-G,Dn	Saginaw Bay
1973	Chartrand, T.A.	D,Ch,B-G	Saginaw Bay
1973	Munawar, M. and I.F. Munawar	D,Ch,Cr,Dn	Lake Huron
1973	Neil, J.H. <u>In: Ont. Water Res. Comm.</u>	G	Georgian Bay, Lake Huron
1973	Schelske, C.L. and J.C. Roth	D,G,Ch,B-G,Dn	Saginaw Bay, Lake Huron
1974	Freedman, P.	G,B-G,Dn	Saginaw Bay
1974	Limnatics, Inc.	D	Lake Huron
1974	Robinson, J.	G	Harbor Beach, Mi.-Lake Huron
1974	Schelske, C.L. <u>et al.</u>	D,B-G	Saginaw Bay, Lake Huron
1974	Vollenweider, R.A. <u>et al.</u>	D,Cr,B-G,Dn	Saginaw Bay, Lake Huron
1974	Young, D.C.	D	Georgian Bay
1975	Great Lakes Water Quality Board	G	Lake Huron
1975	Lowe, R.L.	D	Lake Huron
1975	Munawar, M. and I.F. Munawar	D,Ch,Cr,B-G,Dn	Lake Huron
1975	Neil, J.H. <u>In: Shear, H.</u>	G	Saginaw Bay, Lake Huron
1975	Nicholls, K.H. <u>et al.</u>	D,G,Cr,B-G,E,Dn	Georgian Bay
1975	Patrick, R. and C.W. Reimer	D	Mackinaw Is.-Lake Huron
1975	Stoermer, E.F.	D,G,Cr,B-G,Dn	Saginaw Bay, Lake Huron

# Appendix I. (continued)

1976	Lowe, R.L.	D,G,Chl,Ch,Cr,B-G,E,Dn	Lake Huron
1976	Stoermer <i>et al.</i> In: Schelske <i>et al.</i>	D,G,Ch,Cr,B-G,Dn	Straits of Mackinac
1976	Mich. Water Res. Comm.	D,G,Ch,Cr,B-G	Thunder Bay
1977	Friedrich, P.D. and Lin, C.K.	D	Lake Huron
1977	Sicko-Goad, L. <i>et al.</i>	D,Cr,B-G,E,Dn,H	Saginaw Bay
1977	Stoermer E.F. and Sicko-Goad, L.	Ch,H	Saginaw Bay
1977	Nicholls, K.H. <i>et al.</i>	D,G,Ch,Cr,B-G,E,Dn	Georgian Bay
1978	Stoermer, E.F.	D,G,Ch,Cr,B-G,E,Dn	Lake Huron
1978	Lin, C.K. and Schelske, C.L.	D,G,Ch,Cr,B-G	Lake Huron
1979	Munawar, M. and Munawar, I.F. (a)	D,G,Ch,Cr,B-G,Dn	Lake Huron
1979	Munawar, M. and Munawar, I.F. (b)	D,G,Ch,Cr,B-G,Dn	Geo. Bay, N. Channel
1980	Davis, C.O. <i>et al.</i>	D	Lake Huron
1980	Stoermer, E.F.	D	Lake Huron
1980	Stoermer, E.F. <i>et al.</i>	D,G,Ch,Cr,B-G,E,H	Saginaw Bay
1980	Stoermer, E.F. and Kreis, R.G., Jr.	D,G,Ch,Cr,B-G,E,Dn	Southern Lake Huron
1981	Burton, T.	D	Thunder Bay
1981	Theriot, E.C. and Stoermer, E.F.	D	Lake Huron
1981	Stoermer, E.F. <i>et al.</i>	D	Lake Huron and Saginaw Bay
1981	Munawar, M. and Munawar, I.F.	D,G,Ch,Cr,B-G,Dn	Lake Huron
1982	Munawar, M. and Munawar, I.F.	D,G,Ch,Cr,B-G,Dn	Lake Huron
1982	Stoermer, E.F. <i>et al.</i>	D,G,Ch,Cr,B-G,E,Dn,H	Saginaw Bay
1982	Stoermer, E.F. and Ladewski, T.B.	D	Mackinaw Is.
1982	Ladewski, B.G. <i>et al.</i>	D,G,Ch,Cr,B-G,Dn	Port Huron and Thunder Bay
1982	Theriot, E.C. and Stoermer, E.F.	D	Saginaw Bay
1982	Stevenson, R.J. and Stoermer, E.F. (a)	D,G,B-G,R	Harbor Beach, Mi.
1982	Stevenson, R.J. and Stoermer, E.F. (b)	D,G	Harbor Beach, Mi.
1982	Stevenson, R.J. and Stoermer, E.F. (c)	D,G	Harbor Beach, Mi.
1982	Sheath, R.G. and Morrison, M.O.	D,G,B-G,R	Lake Huron and Georgian Bay
1982	Canale, R.P. <i>et al.</i>	G	Harbor Beach, Mi.
1982	Canale, R.P. and Auer, M.T. (a)	G	Harbor Beach, Mi.
1982	Canale, R.P. and Auer, M.T. (b)	G	Harbor Beach, Mi.
1982	Lekan, J.F. and Coney, T.A.	G	Harbor Beach, Mi.
1982	Jackson, M.B. and Hamdy, Y.S.	G	Georgian Bay
1982	Anderson, M.L. <i>et al.</i>	G	Harbor Beach, Mi.
1982	Auer, M.T. <i>et al.</i>	G	Harbor Beach, Mi.
1982	Auer, M.T. and Canale, R.P. (a)	G	Harbor Beach, Mi.
1982	Auer, M.T. and Canale, R.P. (b)	G	Harbor Beach, Mi.
1982	Graham, J.M. <i>et al.</i>	G	Harbor Beach, Mi.
1983	Kreis, R.G., Jr. <i>et al.</i>	D,G,Ch,Cr,B-G,E,Dn	Straits of Mackinac
1983	Stoermer, E.F. and Theriot, E.C.	D,G,Ch,Cr,B-G,E,Dn,H	Saginaw Bay

## Legend

D	diatoms	Bacillariophyta	B-G	blue-green algae	Cyanophyta
Chl	chloromonads	Chloromonophyta	E	euglenoids	Euglenophyta
G	green algae	Chlorophyta	Dn	dinoflagellates	Pyrrhophyta
Ch	chrysophytes	Chrysophyta	X	yellow-green algae	Xanthophyta
Cr	cryptomonads	Cryptophyta	H	haptophytes	Haptophyta
			R	red algae	Rhodophyta

# Appendix I. (continued)

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Appendix II. Species encountered in southern Lake Huron, 1980.

CYANOPHYTA

name	number slides	average density	average % pop.	maximum density	maximum % pop.
<i>Agmenellum quadruplicatum</i> (Menegh.) Bréb.	5	4.698	0.211	753.982	32.877
<i>Anabaena flos-aquae</i> (Lyngb.) Bréb.	10	1.108	0.066	146.608	5.573
<i>Anabaena</i> spp.	4	0.501	0.016	90.059	2.321
<i>Anacystis cyanea</i> (Kütz.) Dr. and Daily	3	2.062	0.077	209.439	8.919
<i>Anacystis incerta</i> (Lemm.) Dr. and Daily	93	152.963	6.479	2611.709	62.980
<i>Anacystis</i> spp.	6	0.162	0.010	10.472	0.897
<i>Anacystis thermalis</i> (Menegh.) Dr. and Daily	99	28.901	1.491	353.952	25.224
<i>Chroococcus dispersus</i> var. minor G.M. Sm.	16	8.297	0.421	586.430	22.690
<i>Dactylococcopsis acicularis</i> Lemm.	31	0.372	0.023	8.378	0.756
<i>Dactylococcopsis fascicularis</i> Lemm.	2	0.097	0.006	16.755	0.894
<i>Dactylococcopsis smithii</i> Chod. and Chod.	1	0.340	0.010	87.965	2.536
<i>Dactylococcopsis</i> spp.	2	0.040	0.005	8.378	1.015
<i>Gomphosphaeria lacustris</i> Chod.	74	134.518	5.668	2199.113	64.836
<i>Oscillatoria bornetii</i> (Zukal) Forti	108	52.586	2.795	563.392	24.438
<i>Oscillatoria limnetica</i> Lemm.	6	0.736	0.055	43.982	4.534
<i>Oscillatoria</i> sp. 4	4	0.728	0.054	92.153	9.318
<i>Oscillatoria</i> spp.	10	2.418	0.167	209.439	12.870
<i>Rhabdoderma lineare</i> Schmidle and Lauterb.	2	0.089	0.005	14.661	0.936
<i>Schizothrix calcicola</i> (Ag.) Gom.	70	19.998	1.108	305.781	19.149
Undetermined blue-green colony	3	0.202	0.008	37.699	1.722
Undetermined blue-green filament	18	2.814	0.178	127.758	11.255
Total Blue-green (21 categories)		413.628	18.852		

CHLOROPHYTA

name	number slides	average density	average % pop.	maximum density	maximum % pop.
<i>Ankistrodesmus convolutus</i> Corda	1	0.008	0.001	2.094	0.134
<i>Ankistrodesmus gelifactum</i> (Chod.) Bourr.	5	0.129	0.007	16.755	0.796
<i>Ankistrodesmus setigerus</i> (Schröd.) G.S. West	1	0.008	0.000	2.094	0.050
<i>Ankistrodesmus</i> sp. 1	1	0.008	0.000	2.094	0.129
<i>Ankistrodesmus</i> sp. 3	184	6.089	0.414	56.549	4.193
<i>Ankistrodesmus</i> sp. 4	1	0.065	0.007	16.755	1.905
<i>Ankistrodesmus</i> spp.	30	0.550	0.036	16.755	1.584
<i>Blinuclearia erlensis</i> Tiffany	1	0.016	0.001	4.189	0.292
<i>Botryococcus braunii</i> Kütz.	9	3.793	0.225	471.239	31.690

Appendix II. (continued)

<i>Botryococcus protuberans</i> var. <i>minor</i> G.M. Sm.	2	0.194	0.007	33.510	1.445
<i>Glosterium aciculare</i> T. West	11	0.089	0.005	2.094	0.229
<i>Glosterium</i> spp.	3	0.024	0.001	2.094	0.130
<i>Coccomyxa minor</i> Skuja	31	10.545	0.508	219.911	14.577
<i>Coelastrum microporum</i> Näg.	9	0.396	0.020	18.850	1.413
<i>Cosmarium botrytis</i> Menegh.	4	0.049	0.003	4.189	0.452
<i>Cosmarium depressum</i> (Näg.) Lundell	46	0.453	0.027	6.283	0.397
<i>Cosmarium</i> spp.	7	0.081	0.004	4.189	0.208
<i>Crucigenia irregularis</i> Wille	10	0.477	0.025	18.850	1.170
<i>Crucigenia quadrata</i> Morren	58	8.264	0.491	127.758	11.213
<i>Crucigenia rectangularis</i> (A. Br.) Gay	1	0.146	0.005	37.699	1.423
<i>Crucigenia tetrapedia</i> (Kirchn.) W. and W.	5	0.178	0.009	12.566	0.905
<i>Dictyosphaerium pulchellum</i> Wood	2	1.051	0.064	167.551	11.204
<i>Dictyosphaerium</i> spp.	1	0.065	0.007	16.755	1.818
<i>Elakatothrix gelatinosa</i> Wille	2	0.032	0.001	4.189	0.241
<i>Elakatothrix viridis</i> (Snow) Printz	1	0.016	0.001	4.189	0.147
<i>Elakatothrix</i> spp.	1	0.016	0.001	4.189	0.142
<i>Eutetramorus</i> questionable sp. 1	14	0.623	0.055	27.227	3.774
<i>Eutetramorus</i> spp.	25	1.270	0.065	27.227	2.131
<i>Francela droescheri</i> (Lemm.) G.M. Sm.	2	0.016	0.000	2.094	0.059
<i>Gloeocystis gigas</i> (Kütz.) Lagerh.	1	0.008	0.001	2.094	0.252
<i>Gloeocystis planctonica</i> (W. and W.) Lemm.	164	16.440	0.983	159.174	14.151
<i>Gloeocystis</i> spp.	2	1.253	0.094	320.442	24.094
<i>Golenklnia radiata</i> (Chod.) Wille	35	0.420	0.025	12.566	0.615
<i>Interfilum paradoxum</i> Chod.	1	0.121	0.003	31.416	0.758
<i>Kirchneriella</i> spp.	15	0.218	0.010	8.378	0.317
<i>Lagerhemia ciliata</i> (Lagerh.) Chod.	10	0.146	0.009	8.378	0.435
<i>Lagerhemia quadriseta</i> (Lemm.) G.M. Sm.	32	0.954	0.053	31.416	1.908
<i>Lagerhemia subsalsa</i> Lemm.	9	0.251	0.014	16.755	0.604
<i>Lagerhemia</i> spp.	2	0.024	0.001	4.189	0.110
<i>Mougeotia</i> sp. 1	17	0.388	0.019	12.566	0.682
<i>Nephrocyclium agardhianum</i> Näg.	1	0.032	0.002	8.378	0.635
<i>Nephrocyclium</i> spp.	8	0.226	0.016	16.755	1.329
<i>Oocystis parva</i> W. and W.	1	0.057	0.004	14.661	0.910
<i>Oocystis pusilla</i> Hansg.	3	0.097	0.005	8.378	0.507
<i>Oocystis solitaria</i> Witttr.	2	0.016	0.001	2.094	0.147
<i>Oocystis</i> spp.	139	8.661	0.478	92.153	5.927
<i>Pediastrum boryanum</i> (Turp.) Menegh.	8	1.084	0.049	71.209	4.040
<i>Pediastrum duplex</i> Meyen	1	0.388	0.014	100.531	3.753
<i>Pediastrum tetras</i> (Ehr.) Ralfs	3	0.089	0.005	8.378	0.897
<i>Pediastrum</i> spp.	3	0.065	0.002	12.566	0.375
<i>Pedinomonas minutissima</i> Skuja	2	0.243	0.017	62.832	4.329
<i>Quadrigula lacustris</i> (Chod.) G.M. Sm.	1	0.032	0.002	8.378	0.559
<i>Quadrigula</i> spp.	2	0.065	0.003	10.472	0.642
<i>Scenedesmus abundans</i> (Kirchn.) Chod.	6	0.162	0.010	8.378	0.763

Appendix II. (continued)

<i>Scenedesmus acuminatus</i> (Lagerh.) Chod.	3	0.073	0.002	8.378	0.370
<i>Scenedesmus acutus</i> Meyen	2	0.057	0.002	8.378	0.246
<i>Scenedesmus armatus</i> (Chod.) G.M. Sm.	5	0.113	0.004	8.378	0.370
<i>Scenedesmus armatus</i> var. <i>bolgarlensis</i> fo. <i>semicostatus</i> Hortob.	1	0.032	0.001	8.378	0.192
<i>Scenedesmus bicellularis</i> Chod.	55	1.261	0.064	25.133	1.216
<i>Scenedesmus bljugae</i> (Turp.) Lagerh.	16	0.728	0.041	25.133	2.094
<i>Scenedesmus carinatus</i> (Lemm.) Chod.	5	0.162	0.005	16.755	0.516
<i>Scenedesmus costato-denticulatus</i> Hortob.	1	0.016	0.001	4.189	0.214
<i>Scenedesmus denticulatus</i> Lagerh.	1	0.032	0.001	8.378	0.192
<i>Scenedesmus longus</i> Meyen	1	0.032	0.001	8.378	0.234
<i>Scenedesmus opoliensis</i> P. Richt.	1	0.032	0.002	8.378	0.509
<i>Scenedesmus quadricauda</i> (Turp.) Bréb.	38	1.650	0.068	46.077	1.093
<i>Scenedesmus quadricauda</i> var. <i>longispina</i> (Chod.) G.M. Sm.	1	0.032	0.001	8.378	0.370
<i>Scenedesmus quadricauda</i> var. <i>longispina</i> fo. <i>asymetricus</i> (Hortob.) Uherkov.	1	0.032	0.001	8.378	0.317
<i>Scenedesmus quadricauda</i> var. <i>quadricauda</i> (Chod.) G.M. Sm.	10	0.404	0.015	16.755	0.678
<i>Scenedesmus quadricauda</i> var. 1	1	0.049	0.001	12.566	0.352
<i>Scenedesmus serratus</i> (Chod.) Bohlin	11	0.315	0.009	16.755	0.400
<i>Scenedesmus spinosus</i> Chod.	4	0.251	0.006	35.605	0.825
<i>Scenedesmus</i> spp.	46	2.749	0.108	98.436	2.710
<i>Selenastrum</i> spp.	1	0.008	0.000	2.094	0.080
<i>Sphaerocystis Schroeteri</i> Chod.	4	0.477	0.027	50.265	4.660
<i>Staurastrum paradoxum</i> Meyen	2	0.016	0.001	2.094	0.092
<i>Tetradesmus wisconsinense</i> G.M. Sm.	1	0.032	0.002	8.378	0.600
<i>Tetraedron minimum</i> var. <i>apiculato-scorbiculatum</i> (Reinsch, Lagerh.) Skuja	7	0.057	0.003	2.094	0.220
<i>Tetraedron minimum</i> (A. Br.) Hansg.	31	0.315	0.017	6.283	0.353
<i>Tetraedron regulare</i> var. <i>incus</i> Teil.	1	0.008	0.000	2.094	0.069
<i>Tetraedron</i> spp.	1	0.008	0.000	2.094	0.101
<i>Tetrastrum staurogaleiforme</i> (Schröd.) Lemm.	1	0.032	0.002	8.378	0.483
<i>Treubarla setigerum</i> (Archer) G.M. Sm.	1	0.008	0.000	2.094	0.062
<i>Treubarla</i> spp.	11	0.113	0.007	4.189	0.377
<i>Ulothrix</i> spp.	4	0.243	0.015	37.699	3.141
<i>Ulothrix variabilis</i> Kütz.	1	0.154	0.008	39.793	2.067
<i>Ulothrix zonata</i> (Weber and Mohr.) Kütz.	1	0.057	0.002	14.661	0.567
Undetermined green colony	20	1.108	0.074	41.888	2.360
Undetermined green filament	12	1.350	0.085	67.021	4.672
Undetermined green filament sp. 1	2	0.194	0.008	35.605	1.616
Undetermined green filament sp. 5	80	17.192	0.942	303.687	14.642
Undetermined green individual	60	0.930	0.063	16.755	1.527
Total Green (92 categories)		96.672	5.413		

Appendix II. (continued)

BACILLARIOPHYTA	name	number slides	average		maximum	
			density	% pop.	density	% pop.
	<i>Achnanthes affinis</i> Grun.	8	0.065	0.004	2.094	0.242
	<i>Achnanthes blasolettiana</i> (Kütz.) Grun.	7	0.065	0.003	4.189	0.264
	<i>Achnanthes blasetti</i> Germain	1	0.008	0.000	2.094	0.077
	<i>Achnanthes clevei</i> Grun.	1	0.016	0.000	4.189	0.099
	<i>Achnanthes clevei</i> var. <i>rostrata</i> Hust.	4	0.032	0.002	2.094	0.154
	<i>Achnanthes conspicua</i> A. Mayer	1	0.008	0.001	2.094	0.134
	<i>Achnanthes deflexa</i> var. 1	1	0.008	0.000	2.094	0.077
	<i>Achnanthes exigua</i> Grun.	2	0.016	0.000	2.094	0.081
	<i>Achnanthes exigua</i> var. <i>heterovalva</i> Krasske	1	0.008	0.000	2.094	0.050
	<i>Achnanthes flexella</i> (Kütz.) Brun	1	0.008	0.000	2.094	0.047
	<i>Achnanthes lanceolata</i> (Bréb.) Grun.	1	0.008	0.000	2.094	0.059
	<i>Achnanthes lapponica</i> var. <i>ninckei</i> (Guerm. and Mang.) Reim.	3	0.024	0.002	2.094	0.220
	<i>Achnanthes linearis</i> (W. Sm.) Grun.	4	0.040	0.002	4.189	0.285
	<i>Achnanthes microcephala</i> (Kütz.) Grun.	5	0.049	0.002	4.189	0.162
	<i>Achnanthes minutissima</i> Kütz.	26	0.364	0.016	8.378	0.534
	<i>Achnanthes minutissima</i> var. <i>cryptocephala</i> Grun.	5	0.049	0.003	4.189	0.420
	<i>Achnanthes pinnata</i> Hust.	5	0.040	0.001	2.094	0.095
	<i>Achnanthes suchlandti</i> Hust.	1	0.016	0.000	4.189	0.094
	<i>Achnanthes</i> spp.	47	0.841	0.045	23.038	1.469
	<i>Actinocyclus normanii</i> fo. <i>subsalsus</i> (Juhl.-Dannf.) Hust.	1	0.024	0.001	6.283	0.149
	<i>Amphipleura pellucida</i> Kütz.	1	0.008	0.000	2.094	0.060
	<i>Amphora fonticola</i> Mail.	1	0.008	0.001	2.094	0.144
	<i>Amphora ovalis</i> (Kütz.) Kütz.	4	0.040	0.001	4.189	0.128
	<i>Amphora ovalis</i> var. <i>affinis</i> (Kütz.) V.H.	2	0.024	0.001	4.189	0.099
	<i>Amphora ovalis</i> var. <i>pediculus</i> (Kütz.) V.H.	4	0.032	0.001	2.094	0.097
	<i>Amphora perpusilla</i> (Grun.) Grun.	38	0.550	0.026	12.566	0.513
	<i>Amphora thumensis</i> (Mayer) A. Cl.	1	0.008	0.000	2.094	0.048
	<i>Amphora</i> spp.	7	0.129	0.005	14.661	0.347
	<i>Anomeoneis vitrea</i> (Grun.) Ross	2	0.016	0.002	2.094	0.276
	<i>Anomeoneis vitrea</i> var. 1	1	0.008	0.000	2.094	0.059
	<i>Asterionella formosa</i> Hass.	198	32.167	2.041	222.006	15.296
	<i>Caloneis lewisii</i> Patr.	1	0.008	0.000	2.094	0.048
	<i>Caloneis ventricosa</i> var. <i>minuta</i> (Grun.) Patr.	1	0.008	0.001	2.094	0.264
	<i>Caloneis ventricosa</i> var. <i>truncatula</i> (Grun.) Meist.	1	0.016	0.001	4.189	0.350
	<i>Caloneis ventricosa</i> var. 2	1	0.008	0.001	2.094	0.151
	<i>Cocconeis diminuta</i> Pant.	14	0.154	0.006	8.378	0.200
	<i>Cocconeis pediculus</i> Ehr.	1	0.008	0.000	2.094	0.077

Appendix II. (continued)

<i>Cocconeis placentula</i> var. <i>euglypta</i> (Ehr.) Cl.	1	0.008	0.000	2.094	0.050
<i>Cocconeis</i> spp.	1	0.032	0.001	8.378	0.319
<i>Cyclotella antiqua</i> W. Sm.	2	0.016	0.001	2.094	0.147
<i>Cyclotella atomus</i> Hust.	1	0.008	0.000	2.094	0.050
<i>Cyclotella comensis</i> Grun.	259	295.959	16.882	1851.444	80.272
<i>Cyclotella comensis</i> auxospore	11	0.097	0.006	4.189	0.385
<i>Cyclotella comta</i> auxospore	1	0.008	0.001	2.094	0.158
<i>Cyclotella comta</i> (Ehr.) Kütz.	100	2.571	0.149	39.793	1.709
<i>Cyclotella meneghiniana</i> Kütz.	3	0.024	0.001	2.094	0.101
<i>Cyclotella meneghiniana</i> Skv.	112	2.385	0.115	33.510	1.229
<i>Cyclotella ocellata</i> Pant.	203	14.087	0.954	69.115	7.310
<i>Cyclotella ocellata</i> auxospore	2	0.016	0.001	2.094	0.137
<i>Cyclotella operculata</i> (Ag.) Kütz.	6	0.049	0.002	2.094	0.122
<i>Cyclotella pseudostelligera</i> Hust.	58	2.523	0.170	43.982	3.119
<i>Cyclotella stelligera</i> (Cl. and Grun.) V.H.	230	16.076	1.151	100.531	9.635
<i>Cyclotella</i> sp. 5	4	0.073	0.004	10.472	0.513
<i>Cyclotella</i> spp. auxospore	46	0.558	0.030	10.472	0.609
<i>Cymatopleura solea</i> (Bréb. and Godey) W. Sm.	2	0.024	0.001	4.189	0.156
<i>Cymatopleura solea</i> var. <i>apiculata</i> (W. Sm.) Ralfs	1	0.008	0.000	2.094	0.128
<i>Cymbella cistula</i> (Ehr.) Kirchn.	3	0.024	0.001	2.094	0.081
<i>Cymbella cuspidata</i> var. <i>schulzii</i> A. Cl.	1	0.008	0.000	2.094	0.050
<i>Cymbella delicatula</i> Kütz.	4	0.032	0.002	2.094	0.175
<i>Cymbella hybrida</i> Grun.	1	0.008	0.000	2.094	0.059
<i>Cymbella microcephala</i> Grun.	44	0.606	0.030	10.472	1.050
<i>Cymbella microcephala</i> var. <i>crassa</i> Reim.	2	0.016	0.001	2.094	0.156
<i>Cymbella minuta</i> Hilse	19	0.291	0.013	14.661	0.525
<i>Cymbella prostrata</i> var. <i>auerswaldii</i> (Rabh.) Reim.	1	0.008	0.001	2.094	0.154
<i>Cymbella trianguulum</i> (Ehr.) Cl.	1	0.008	0.000	2.094	0.038
<i>Cymbella</i> sp. 21	1	0.008	0.001	2.094	0.175
<i>Cymbella</i> spp.	7	0.081	0.005	6.283	0.454
<i>Denticula tenuis</i> var. <i>crassula</i> (Näg. and Kütz.) W. and G.S. West	14	0.186	0.011	10.472	0.781
<i>Diatoma tenue</i> Ag.	10	0.251	0.012	14.661	0.752
<i>Diatoma tenue</i> var. <i>elongatum</i> Lyngb.	86	5.450	0.270	142.419	4.916
<i>Diatoma tenue</i> var. <i>pachycephala</i> Grun.	6	0.202	0.010	16.755	1.040
<i>Diploneis parva</i> Cl.	1	0.008	0.000	2.094	0.077
<i>Diploneis</i> spp.	1	0.008	0.000	2.094	0.052
<i>Entomoneis ornata</i> (J.W. Bail.) Reim.	1	0.016	0.000	4.189	0.100
<i>Epithemia</i> spp.	1	0.008	0.000	2.094	0.042
<i>Fragilaria brevistriata</i> Grun.	11	0.590	0.022	43.982	1.481
<i>Fragilaria capucina</i> Desm.	41	45.979	1.365	3279.821	52.287
<i>Fragilaria construens</i> (Ehr.) Grun.	16	1.690	0.058	159.174	3.689

Appendix II. (continued)

<i>Fragilaria construens</i> var. <i>minuta</i> Temp. and Per.	116	2.887	0.175	25.133	1.681
<i>Fragilaria construens</i> var. <i>pumila</i> Grun.	13	0.712	0.020	52.360	1.465
<i>Fragilaria construens</i> var. <i>venter</i> (Ehr.) Grun.	10	0.687	0.019	50.265	1.407
<i>Fragilaria crotonensis</i> Kitton	164	56.224	2.992	647.167	29.382
<i>Fragilaria crotonensis</i> var. <i>oregona</i> Sov.	1	0.121	0.006	31.416	1.632
<i>Fragilaria intermedia</i> Grun.	2	0.032	0.001	4.189	0.267
<i>Fragilaria intermedia</i> var. <i>fallax</i> (Grun.) A. Cl.	38	3.590	0.228	90.059	9.641
<i>Fragilaria leptostauron</i> (Ehr.) Hust.	6	0.105	0.004	6.283	0.292
<i>Fragilaria leptostauron</i> var. <i>dubia</i> (Grun.) Hust.	1	0.008	0.000	2.094	0.097
<i>Fragilaria plinnata</i> Ehr.	58	8.183	0.290	219.911	9.981
<i>Fragilaria plinnata</i> var. <i>intercedens</i> (Grun.) Hust.	1	0.194	0.009	50.265	2.414
<i>Fragilaria plinnata</i> var. <i>lancettula</i> (Schum.) Hust.	22	2.491	0.096	85.870	4.236
<i>Fragilaria</i> spp.	34	0.784	0.038	25.133	0.937
<i>Fragilaria vaucheriae</i> (Kütz.) Peters.	22	0.235	0.013	4.189	0.448
<i>Fragilaria vaucheriae</i> var. <i>capitellata</i> (Grun.) Patr.	15	0.251	0.012	12.566	0.480
<i>Gomphonema gracile</i> Ehr.	1	0.008	0.000	2.094	0.065
<i>Gomphonema intricatum</i> Kütz.	2	0.016	0.000	2.094	0.048
<i>Gomphonema olivaceum</i> (Lyngb.) Kütz.	1	0.008	0.000	2.094	0.054
<i>Gomphonema</i> spp.	4	0.032	0.001	2.094	0.090
<i>Gyrosigma attenuatum</i> (Kütz.) Rabh.	1	0.008	0.000	2.094	0.071
<i>Melosira distans</i> var. <i>alpicola</i> Grun.	8	0.154	0.008	12.566	0.952
<i>Melosira granulata</i> (Ehr.) Ralfs	9	0.574	0.022	33.510	1.527
<i>Melosira granulata</i> alpha status (Ehr.) Ralfs	6	0.299	0.008	27.227	0.631
<i>Melosira granulata</i> var. <i>angustissima</i> O. Müll.	3	0.340	0.011	69.115	1.963
<i>Melosira islandica</i> O. Müll.	105	12.178	0.714	123.569	7.818
<i>Melosira italica</i> subsp. <i>subarctica</i> O. Müll.	17	0.784	0.048	39.793	2.770
<i>Navicula anglica</i> var. <i>signata</i> Hust.	1	0.008	0.000	2.094	0.050
<i>Navicula anglica</i> Ralfs.	1	0.008	0.000	2.094	0.050
<i>Navicula bacillum</i> Ehr.	1	0.008	0.001	2.094	0.151
<i>Navicula capitata</i> Ehr.	2	0.016	0.001	2.094	0.081
<i>Navicula capitata</i> var. <i>luneburgensis</i> (Grun.) Patr.	1	0.008	0.000	2.094	0.044
<i>Navicula cryptocephala</i> var. <i>veneta</i> (Kütz.) Rabh.	2	0.016	0.001	2.094	0.154
<i>Navicula cryptocephala</i> Kütz.	12	0.113	0.005	4.189	0.184
<i>Navicula decussis</i> Östr.	1	0.008	0.001	2.094	0.224
<i>Navicula menisculus</i> var. <i>upsallensis</i> Grun.	1	0.008	0.000	2.094	0.048
<i>Navicula nyassensis</i> fo. <i>minor</i> O. Müll.	1	0.008	0.000	2.094	0.050
<i>Navicula ordinaria</i> Hust.	1	0.008	0.000	2.094	0.050

Appendix II. (continued)

<i>Navicula platystoma</i> var. <i>pantocsekii</i> Wils. and Kolbe	1	0.008	0.001	2.094	0.151
<i>Navicula pupula</i> Kütz.	2	0.016	0.000	2.094	0.065
<i>Navicula radiosa</i> Kütz.	7	0.065	0.003	4.189	0.189
<i>Navicula radiosa</i> var. <i>parva</i> Wallace	3	0.024	0.001	2.094	0.133
<i>Navicula radiosa</i> var. <i>tenella</i> (Bréb.) Grun.	9	0.073	0.004	2.094	0.276
<i>Navicula tripunctata</i> var. <i>schizonemoides</i>	1	0.008	0.000	2.094	0.059
<i>Navicula</i> sp. 44	6	0.065	0.002	6.283	0.151
<i>Navicula</i> spp. (V.H.) Patr.	35	0.550	0.029	18.850	0.937
<i>Neidium</i> spp.	1	0.008	0.000	2.094	0.096
<i>Nitzschia acicularis</i> (Kütz.) W. Sm.	118	3.639	0.189	69.115	1.702
<i>Nitzschia acuta</i> Hantz.	16	0.202	0.010	8.378	0.367
<i>Nitzschia angustata</i> var. <i>acuta</i> Grun.	11	0.129	0.008	6.283	0.673
<i>Nitzschia apiculata</i> (Greg.) Grun.	1	0.008	0.000	2.094	0.054
<i>Nitzschia bacata</i> Hust.	7	0.073	0.003	6.283	0.243
<i>Nitzschia capitellata</i> Hust.	11	0.097	0.007	4.189	0.267
<i>Nitzschia confinis</i> Hust.	32	0.485	0.024	14.661	0.679
<i>Nitzschia dentacula</i> Grun.	4	0.040	0.002	4.189	0.281
<i>Nitzschia dissipata</i> (Kütz.) Grun.	47	0.606	0.034	14.661	0.933
<i>Nitzschia dissipata</i> var. <i>media</i> Grun.	2	0.016	0.001	2.094	0.140
<i>Nitzschia fonticola</i> Grun.	23	0.380	0.017	10.472	0.385
<i>Nitzschia frustulum</i> (Kütz.) Grun.	1	0.016	0.002	4.189	0.431
<i>Nitzschia gracilis</i> Hantz.	29	0.493	0.020	18.850	0.446
<i>Nitzschia holterupensis</i> Foged	4	0.057	0.003	4.189	0.368
<i>Nitzschia impressa</i> Hust.	1	0.057	0.002	14.661	0.543
<i>Nitzschia insecta</i> Hust.	1	0.008	0.000	2.094	0.080
<i>Nitzschia linearis</i> W. Sm.	1	0.016	0.000	4.189	0.099
<i>Nitzschia macilenta</i> Greg.	1	0.008	0.001	2.094	0.182
<i>Nitzschia palea</i> (Kütz.) W. Sm.	17	0.275	0.014	20.944	0.611
<i>Nitzschia pura</i> Hust.	2	0.016	0.000	2.094	0.065
<i>Nitzschia sigmoides</i> (Nitz.) W. Sm.	12	0.202	0.009	6.283	0.546
<i>Nitzschia spiculoides</i> Hust.	3	0.032	0.002	4.189	0.216
<i>Nitzschia subcapitellata</i> Hust.	2	0.016	0.001	2.094	0.216
<i>Nitzschia tryblionella</i> var. <i>levdensis</i> (W. Sm.) Grun.	1	0.008	0.001	2.094	0.144
<i>Nitzschia</i> sp. 1	2	0.024	0.001	4.189	0.218
<i>Nitzschia</i> sp. 19	10	0.105	0.005	4.189	0.324
<i>Nitzschia</i> sp. 2	11	0.267	0.014	43.982	2.234
<i>Nitzschia</i> sp. 32	96	1.860	0.115	14.661	1.040
<i>Nitzschia</i> spp.	109	3.178	0.171	50.265	3.077
<i>Opephora martyi</i> Hérrib.	2	0.016	0.001	2.094	0.080
<i>Rhizosolenia eriensis</i> H.L. Sm.	205	29.013	1.708	297.404	15.656
<i>Rhizosolenia gracilis</i> H.L. Sm.	55	2.022	0.089	73.304	2.292
<i>Rhizosolenia curvata</i> (Kütz.) Grun.	1	0.008	0.000	2.094	0.119

Appendix II. (continued)

<i>Skeletonema potamos</i> (Weber) Hasle	1	0.073	0.002	18.850	0.464
<i>Stauroneis smithii</i> Grun.	1	0.008	0.000	2.094	0.076
<i>Stephanodiscus alpinus</i> Hust.	31	0.566	0.025	35.605	1.121
<i>Stephanodiscus blinderanus</i> (Kütz.) Krieg.	10	1.035	0.040	85.870	2.520
<i>Stephanodiscus hantzschii</i> Grun.	86	1.569	0.089	23.038	1.292
<i>Stephanodiscus minutus</i> Grun. ex Cl. and Moll.	145	10.545	0.654	100.531	8.818
<i>Stephanodiscus niagarae</i> Ehr.	13	0.218	0.008	16.755	0.478
<i>Stephanodiscus subtilis</i> (Van Goor) A. Cl.	11	1.286	0.062	192.684	8.663
<i>Stephanodiscus tenuis</i> Hust.	4	0.049	0.002	4.189	0.237
<i>Stephanodiscus transilvanicus</i> Pant.	5	0.049	0.003	4.189	0.275
<i>Stephanodiscus</i> sp. 5	1	0.008	0.001	2.094	0.224
<i>Stephanodiscus</i> sp. 6	1	0.016	0.000	4.189	0.099
<i>Stephanodiscus</i> spp.	10	0.097	0.007	4.189	0.377
<i>Surirella angusta</i> Kütz.	12	0.129	0.006	6.283	0.302
<i>Surirella ovata</i> Kütz.	5	0.057	0.002	4.189	0.166
<i>Surirella ovata</i> var. <i>pinnata</i> (W. Sm.) Rabh.	2	0.024	0.001	4.189	0.121
<i>Surirella</i> spp.	1	0.032	0.002	8.378	0.442
<i>Synedra acus</i> Kütz.	2	0.032	0.001	6.283	0.134
<i>Synedra cycloptum</i> Brutschy	9	0.162	0.010	16.755	0.906
<i>Synedra delicatissima</i> W. Sm.	1	0.008	0.001	2.094	0.189
<i>Synedra filiformis</i> var. <i>exilis</i> A. Cl.	2	0.024	0.002	4.189	0.289
<i>Synedra filiformis</i> Grun.	182	19.714	0.978	318.348	7.839
<i>Synedra minuscula</i> Grun.	81	2.943	0.141	98.436	3.610
<i>Synedra minuscula</i> abnormal	1	0.008	0.000	2.094	0.079
<i>Synedra ostenfeldii</i> (Krieg.) A. Cl.	113	3.429	0.193	29.322	1.491
<i>Synedra ostenfeldii</i> abnormal	3	0.024	0.001	2.094	0.195
<i>Synedra parasitica</i> (W. Sm.) Hust.	7	0.218	0.009	18.850	0.775
<i>Synedra tenera</i> W. Sm.	3	0.024	0.001	2.094	0.099
<i>Synedra ulna</i> var. <i>chaseana</i> Thomas	51	0.817	0.041	12.566	0.823
<i>Synedra ulna</i> (Nitz.) Ehr.	5	0.057	0.002	6.283	0.178
<i>Synedra</i> spp.	36	0.631	0.030	54.454	1.341
<i>Tabellaria fenestrata</i> (Lyngb.) Kütz.	169	31.900	1.818	251.327	19.560
<i>Tabellaria fenestrata</i> var. <i>geniculata</i> A. Cl.	7	0.558	0.040	43.982	4.094
<i>Tabellaria flocculosa</i> (Roth) Kütz.	22	1.245	0.063	41.888	1.663
<i>Tabellaria flocculosa</i> var. <i>linearis</i> Koppen	116	11.248	0.615	134.041	7.748
Undetermined centric diatom spp.	3	0.024	0.001	2.094	0.143
Undetermined pennate diatom spp.	1	0.008	0.001	2.094	0.189
Total Diatoms (194 categories)		649.019	35.516		

Appendix II. (continued)

CHRYSOPHYTA						
name	number slides	average density	average % pop.	density	maximum % pop.	
<i>Bodo</i> spp.	1	0.008	0.000	2.094	0.123	
<i>Centritractus</i> spp.	1	0.008	0.000	2.094	0.103	
<i>Chrysamoeba radians</i> Klebs	1	0.008	0.001	2.094	0.191	
<i>Chrysochromulina parva</i> Lackey	2	0.032	0.001	6.283	0.175	
<i>Chrysococcus dokidophorus</i> Pasch.	149	3.574	0.266	50.265	6.630	
<i>Chrysococcus rufescens</i> Klebs	72	1.173	0.066	18.850	0.939	
<i>Chrysophycean</i> cyst	8	0.113	0.010	8.378	1.329	
<i>Chrysosphaerella flagellate</i> spp.	152	7.585	0.524	81.681	8.409	
<i>Chrysosphaerella longispina</i> Lauterb.	57	25.941	1.396	630.412	41.008	
<i>Diceras</i> spp.	1	0.008	0.001	2.094	0.292	
<i>Dinobryon bavaricum</i> Imhof	8	0.768	0.054	56.549	5.253	
<i>Dinobryon cylindricum</i> Imhof	4	0.445	0.023	48.171	2.323	
<i>Dinobryon cylindricum</i> statospore	31	1.278	0.052	43.982	2.329	
<i>Dinobryon</i> cyst	65	1.189	0.065	25.133	1.648	
<i>Dinobryon divergens</i> Imhof	155	26.272	1.418	682.772	24.493	
<i>Dinobryon divergens</i> statospore	1	0.008	0.000	2.094	0.122	
<i>Dinobryon sociale</i> Ehr.	1	0.065	0.004	16.755	1.124	
<i>Dinobryon sociale</i> var. <i>americanum</i> (Brunn.) Bach.	3	0.186	0.017	33.510	2.899	
<i>Dinobryon</i> spp.	2	0.032	0.002	6.283	0.481	
<i>Kephyrion cupuliforme</i> Contr.	1	0.008	0.001	2.094	0.161	
<i>Kephyrion</i> spp.	13	0.121	0.007	4.189	0.295	
<i>Mallomonas caudata</i> Iwan.	1	0.008	0.000	2.094	0.127	
<i>Mallomonas elongata</i> Reverdin	10	0.105	0.006	6.283	0.470	
<i>Mallomonas pseudocoronata</i> Presc.	47	0.655	0.038	10.472	0.967	
<i>Mallomonas</i> sp. 3	2	0.016	0.001	2.094	0.194	
<i>Mallomonas</i> sp. 4	12	0.113	0.006	4.189	0.226	
<i>Mallomonas</i> spp.	2	0.008	0.000	2.094	0.059	
<i>Mallomonas</i> statospore	20	0.202	0.012	6.283	0.299	
<i>Mallomonas tonsurata</i> var. <i>alpina</i> (Pasch. and Rutttn.) Krieg.	45	0.493	0.032	12.566	0.943	
<i>Mallomonas tonsurata</i> Teil.	25	0.251	0.015	6.283	0.450	
<i>Monochrysis aphanaster</i> Skuja	226	6.938	0.409	56.549	2.542	
<i>Ochromonas</i> sp. 2	192	114.964	6.244	678.583	34.933	
<i>Ochromonas</i> spp.	53	0.890	0.051	12.566	0.820	
<i>Pseudokephyrion</i> spp.	4	0.057	0.007	6.283	0.997	
<i>Rhizochrysis limnetica</i> G.M. Sm.	60	0.849	0.047	14.661	0.763	
<i>Spiniferomonas</i> sp.	16	0.243	0.011	10.472	0.535	
<i>Spiniferomonas</i> spp.	98	2.143	0.144	52.360	3.181	

# Appendix II. (continued)

<i>Synura</i> spp.	1	0.518	0.044	134.041	11.307
Undetermined colonial chrysophyte	28	2.563	0.131	58.643	3.152
Undetermined individual chrysophyte	5	0.089	0.007	8.378	1.180
<i>Uroglena</i> sp.	2	0.218	0.007	39.793	1.250
Total Chrysophytes ( 41 categories)		200.153	11.124		

## CRYPTOPHYTA

name	number slides	average density	average % pop.	density maximum	% pop. maximum
<i>Chroomonas nordstedtii</i> Hansg.	10	0.194	0.011	12.566	1.087
<i>Chroomonas</i> spp.	250	23.150	1.344	207.345	7.041
<i>Cryptaulax</i> spp.	7	0.057	0.004	2.094	0.254
<i>Cryptomonas caudata</i> Schiller	3	0.024	0.001	2.094	0.164
<i>Cryptomonas</i> cyst	16	0.178	0.012	4.189	0.714
<i>Cryptomonas erosa</i> Ehr.	7	0.081	0.004	6.283	0.196
<i>Cryptomonas erosa</i> var. <i>reflexa</i> Marsson	3	0.024	0.001	2.094	0.120
<i>Cryptomonas marssonii</i> Skuja	5	0.040	0.003	2.094	0.294
<i>Cryptomonas ovata</i> Ehr.	188	4.237	0.244	58.643	2.104
<i>Cryptomonas pyrenoidifera</i> Geitl.	5	0.057	0.004	4.189	0.378
<i>Cryptomonas reflexa</i> Skuja	2	0.024	0.001	4.189	0.185
<i>Cryptomonas rostratiformis</i> Skuja	2	0.032	0.001	6.283	0.213
<i>Cryptomonas</i> spp.	220	11.022	0.635	50.265	3.046
<i>Rhodomonas minuta</i> Skuja	234	27.363	1.650	171.740	9.314
<i>Rhodomonas minuta</i> var. <i>nannoplantica</i> Skuja	258	75.267	4.865	343.480	25.364
Total Cryptomonads ( 15 categories)		141.751	8.782		

## PYRRHOPHYTA

name	number slides	average density	average % pop.	density maximum	% pop. maximum
<i>Amphidinium</i> spp.	2	0.016	0.001	2.094	0.148
<i>Ceratium hirundinella</i> (O. Müll.) Shrank	19	0.186	0.014	6.283	0.585
Dinoflagellate cyst	1	0.008	0.000	2.094	0.101
<i>Glenodinium</i> spp.	1	0.008	0.000	2.094	0.060
<i>Gymnodinium helveticum</i> Penard	33	0.332	0.018	6.283	0.382
<i>Gymnodinium ordinatatum</i> Skuja	58	0.792	0.041	14.661	0.648
<i>Gymnodinium</i> spp.	146	2.167	0.137	20.944	1.621
<i>Peridinium</i> spp.	7	0.057	0.004	2.094	0.189
<i>Spirodinium pusillum</i> var. <i>minor</i> Skuja	107	1.698	0.109	16.755	0.966
Unidentified dinoflagellate spp.	6	0.065	0.004	4.189	0.448
Total Dinoflagellates ( 11 categories)		5.361	0.330		



